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REVERSE OSMOSIS AS A TREATMENT FOR WASTE WATER

AEROJET-GENERAL CORPORATION, AZUSA, CALIFORNIA

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REVERSE OSMOSIS AS A TREATMENT FOR WASTE WATER

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The application of reverse osmosis to waste water renovation was investigated with respect to product water quality (mineral and organic matter) and production rates. The feasibility of the process was demonstrated unequivocally. A pretreatment technique was also devised for secondary effluent that suppresses membrane flux decay with time and extends the useful life of membranes considerably by removing objectionable components. Cost estimates are included.

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I. SUMMARY

The application of reverse osmosis to waste water renovation has been investigated with respect to product water quality (mineral and organic matter) and production rates.

The feasibility of the process has been demonstrated unequivocally; secondary treatment plant effluent has been used as feed in the production of a purified product averaging less than 80 ppm TDS, less than 0.3 ppm ABS and less than 10 ppm COD. In one test, in which 83% recovery from trickling filter effluent was achieved, the product contained approximately 53 ppm TDS, 0.1 ppm ABS and 10 ppm COD. In another test, 95.6% of the feed was recovered as product.

Several AGC-modified cellulose acetate films have been evaluated for use in this renovation process. The performance of the lower flux films (nominally 20 gal/sq ft-day) was excellent; however, that of the high flux films (nominally 30-60 gal/sq ft-day) dropped by 1/4 to 1/3 within several hours of operation to the performance level of the lower-production-rate films. Films were evaluated at both 750 psig and 1500 psig, the balance between production rate and energy costs favoring the low-pressure process. The production rates achieved at 750 psig are economically attractive.

A pretreatment technique has been devised for secondary effluent which suppresses membrane flux decay with time and extends the useful life of membranes considerably by removing objectionable components.

A cost estimate has been prepared for a 10,000,000 gallon per day production plant. Extrapolating from the laboratory scale data to the large plant and using a standardized cost estimating procedure designed for such extrapolations, it was estimated that high quality water could be produced from secondary effluent at a cost of $0.25/1000 gallons, including amortization of capital investment.

II. INTRODUCTION

The Reverse Osmosis Process involves the application of pressure to an aqueous salt solution on one side of a semipermeable membrane to produce a flow of pure water through the membrane. Significant flow rates are observed when the applied pressure is greater than the osmotic pressure of the saline solution. This principle is illustrated in Figure 1. A special type of cellulosic membrane, developed at Aerojet-General Corporation, is required for this process if useful fluxes of potable water are to be obtained. A great promise of the process is derived from its operation under ambient, isothermal conditions. The energy cost is potentially small because no change of state of water is involved; many processes require the recycle of large quantities of latent heat which, because of inevitable losses, leads to high energy costs.

The Aerojet-General Corporation began investigating the use of cellulose acetate based semipermeable membranes for saline water conversion in mid-1961 on a privately sponsored program. The availability of a useful membrane was the basis for the proposal to initiate the present program which was a study of the application of reverse osmosis to waste water renovation.

During the course of this program, it has been demonstrated unequivocally that the Reverse Osmosis Process is feasible for the production of high quality water* from waste water. A series of tests was carried out at 750 and 1500 psig with membranes tailored for flux and permeation**. Optimum conditions for operation were projected and cost estimates for the ultimate process were made.

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* The quality of water produced during the course of this work was uniformly high and is believed to be potable from both the chemical and biological standpoint. However, the standards for potable water have not been completely established by the Public Health Service from the standpoint of organic contaminants, nor has the biological quality been determined in the present work. As a result, throughout this report, the writers have refrained from using the word potable to describe the excellent quality water derived in the reported work.

** Flux is defined as the rate of flow of product water per unit membrane area, usually in gallons/square foot-day. Permeation is the weight fraction of solute in the product times 100, divided by the weight fraction of solute in the feed in percent, and is usually given in parts per million (ppm).

The Reverse Osmosis Renovation Process, because of its inherent simplicity (Figure 2), appears to be applicable to the unusual requirements imposed by the variations in waste water composition with time and with location. The results of this program have demonstrated the outstanding promise of the process which warrants continued development.

III. WASTE WATER TEST RESULTS

A. EQUIPMENT

The reverse osmosis process equipment used in this study consisted of a water feed tank, a high pressure pump, membrane-support cells, a pressure-regulating device and the necessary lines, valves and gauges to complete the flow system, as shown in Figure 3.

The specific apparatus assembled for the first portion of the water renovation work (Figure 4) consisted of (1) a five-gallon polyethylene feed tank, (2) a Jaeco pump, (3) two sets of fiberglass-epoxy flanges, each capable of supporting 0.5 square foot of membrane area (Figures 5 and 6), (4) 1/4 inch stainless steel tubing coupled with nylon braided flexible hoses, (5) a needle valve, Nupro Cat. No. B-4M and (6) an accumulator, Greer Hydraulic, Part No. A0762-200.

The equipment setup just described was modified for the second part of the study to allow overnight unattended operation. This second equipment setup (Figure 7) utilized a 50-gal fiberglass-epoxy feed tank, the same pressure pump, a 1-gal accumulator (Greer Hydraulic, Model A-621-200) a high-pressure filter (Vasco Valve Co. Model FSA 15-B-471), a pressure control valve (Fisher Governor Co. Type 530) and a pressure controller (Fisher Governor Co. Type 4160). In addition, a tank was installed in the reject stream return line to hold films, portions of which were withdrawn periodically and tested in another reverse osmosis system.

B. TEST PROCEDURES

Secondary treatment plant effluent was obtained for each test from the Azusa Water Reclamation Plant and, prior to use, was filtered through Whatman No. 5 filter paper. The pH of the feed water was adjusted to 3 - 5 by addition of acetic, hydrochloric or sulfuric acids.

Films were fabricated according to standard techniques developed at Aerojet and were mounted in the two cells shown in Figures 5 and 6. A standard test procedure was developed which consisted of (1) pumping waste water through the feed lines at ambient pressure with valves a, b, c, d, 11 open (Figure 3), (no flow takes place across the membrane during this period.) (2) raising the feed-water pressure over a 15-minute interval to the operating range by closing relief valve 11, while discarding product water, and (3) closing by-pass valve c, which forced feed-water to flow through the cell and over the membrane. The completion of the pre-test procedure was considered to occur at zero time and the product water was thereupon collected and removed from the flow system. The residual water in the feed system was recycled; thus, the feed-water concentration was constantly increasing throughout the test and its effects upon product purity and production rates (flux) were noted. In general, tests were discontinued after six to eight hours because it was recognized that biological degradation could sufficiently alter the feed-water composition thereafter to invalidate the results.

Throughout the test, the pH, conductivity and flow rate of both the feed and product streams were determined. Samples of both streams were taken at appropriate intervals for TDS[1], ABS[2], and COD[3] determinations. These samples were withdrawn following initial achievement of steady-state conditions and at approximately twofold, fivefold and tenfold feed-water TDS concentrations as determined by conductivity measurements. Product mineral compositions were determined during two tests to detail more completely the product quality.

Tests were performed at both 750 and 1500 psig. The films tested were tailored to reject 50% to 95% of the dissolved components of the feed-water; i.e., nominal permeations of 5% to 50%.

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1 - Total dissolved solids
2 - Alkylbenzenesulfonate
3 - Chemical oxygen demand

Following the conclusion of the first two series of waste water renovation tests, the equipment was modified as described in the previous section (III A) and continuous operation was begun. For the remainder of the test program, the following procedures were followed: membranes were pre-conditioned by operating them at 750 psig with deionized water, or with 750 ppm salt water until two consecutive sets of fluxes taken 4 - 8 hours apart were within 0.2 gfd. This usually required 4 - 7 days. The waste water (untreated or treated) was then added and the film parameters were measured at least three times daily until the conclusion of the test.

The continuous operation of the equipment afforded the opportunity to study film property changes when the films were exposed to secondary effluent but not to pressure. In order to do this, a film holding box was included in the ambient pressure reject line and a group of films were stored in the box. Samples were removed at intervals for measurement of flux and salt permeation change with time.

The analytical procedures used in the work reported are described in Appendix A.

C. INDIVIDUAL TEST RESULTS

Attempts to carry out experiments on a material as variable as secondary effluent are fraught with difficulties. An enormous variety of both inorganic and organic species is present in waste water, the definition of which is virtually an impossible task. As a result, the quality of water is necessarily defined in terms of broad, inclusive parameters, such as total dissolved solids (TDS), conductivity and chemical oxygen demand (COD). The use of generalized parameters inevitably involves errors; for example, TDS obviously omits volatile components in the description of the total composition of waste water. Chemical oxygen demand is often used to represent the organic content of a waste, but it obviously excludes organic components which are refractory to chemical oxidation under test conditions. Conductivity cannot adequately express the inorganic content in the absence of a complete ion analysis. These difficulties hinder any attempt to achieve an accurate material balance in the experiments reported herein.

During the course of the experiments with waste water, it was found that solid material deposited on the membrane surface. At the end of each experiment, a flocculent tan-to-brown deposit, roughly 2 to 3 mils thick was found on the membrane. These deposits were examined cursorily and found to have the following characteristics: the residue was insoluble and did not evolve gas in acid. It had an extremely unpleasant, putrid odor. After drying samples of solid at 105°C to constant weight, ignition in a muffle furnace at 600°C resulted in a weight loss of 60%; i.e., the 105°C dried residue consisted of 60% organics and volatile inorganics. The remaining 40% (fixed solids) was predominantly iron and contained traces of copper, nickel, calcium, magnesium, silicon and aluminum. Because of the loss in dissolved solids which the deposit represents, and because the accumulated volume of test samples periodically withdrawn for analysis were not negligible when compared with the total feed volume, it was not possible to obtain material balances between feed composition and product composition, nor among TDS, conductivity, COD and ABS. Although the reader will be unable to verify the data through material balances, the validity of the individual data are considered sound by the authors within the limits imposed by the experimental methods.

1. Preliminary Tests

Several preliminary tests were conducted with filtered waste water obtained from the Azusa Water Reclamation Plant. The purposes of these tests were (a) to examine the gross effects of waste water feed upon the process operation and (b) to provide prototype product water for standardization of the analytical procedures.

In the preliminary tests, it was found that product flux rates dropped by 73.5% within three hours with waste water feed. It was also observed that an acid-soluble scale was deposited upon the film and it was demonstrated that this scale would remain soluble in acidified feed water. In Figure 8 and Table 1 are presented data of Test 15 which demonstrated that acidification of the feed reestablished initial flux rates. Note that in four hours of operation with feed water pH of 7.4 to 8.5, the flux fell from an initial value of 16.9 gallons per square foot of membrane surface per day (gfd) to a final value of 4.0 gfd. The feed was

then acidified to pH 4.3 with acetic acid, whereupon the flux increased to 16.8 gfd after 2-3/4 hours; however, there was evidence of membrane degradation at the same time, namely sharp increases in permeation.

It was also observed that the flux rate rose momentarily upon acidification to values slightly higher than those initially observed and that the product water pH was less than that of the feed water pH. It is interesting that under the test conditions, the membrane proved to be more permeable to hydronium than to hydroxyl ion, such that continued additions of acid were necessary to maintain a constant feed water pH. In later tests, it was observed that the product was sometimes more acidic, sometimes more alkaline than the feed.

During the preliminary tests, the water analysis was limited to conductivity, TDS and COD determinations. Conductivity and TDS values were self-consistent but some difficulty was encountered initially with erratic COD values, especially in the low-level determinations. The COD-determination difficulties were resolved during the program and were attributed to contamination from the Tygon tubing used to transfer reagents.

2. Basic Feasibility Study

The first objective of the program entailed establishing the feasibility of the Reverse Osmosis Process in the renovation of waste water. The cell was operated for a nine-hour period starting with 40 liters (10.6 gallons) of filtered (No. 5 Whatman Filter Paper) trickling filter effluent obtained from the Azusa Water Reclamation Plant. The purpose of the test was to demonstrate that the feed water could be concentrated tenfold while maintaining high quality product water at reasonable flux rates. A tenfold increase in feed TDS concentration was indeed achieved. This test (No. 18) was initiated at a feed pH of 7.4; within 1-1/4 hours the product flux rate fell from 25.5 to 10.0 gfd (Figure 9). Thereupon, the feed was acidified with acetic acid and the test was continued with incremental additions of acid as required to maintain the feed pH between 5 and 6. After almost nine hours operation, the flux was 15.0 gfd; at this point the test was discontinued. The following day, the test was resumed with only one cell, and the feed water was concentrated to greater than 5000 ppm TDS. Product conductivity and TDS were satisfactory throughout. The data are summarized in Table 2 and Figure 9 for that cell which was operated to the conclusion of the test.

A modified repetition of the basic feasibility test, No. 28 (Table 3 and Figure 10) was carried out. In this test, 83% of the feed was recovered as purified product during a six hour period. A product taken after 1-1/2 hours was subjected to mineral analysis. The results of mineral analyses for both feasibility tests, as given in Table 4, were found to be well within the acceptable range in all respects.

3. The 750 psig Test Series

The second objective of the program was to determine the flux and contaminant removal capability for six types of films at 750 psig from varying feed concentrations. Six membrane types were tested having nominal water fluxes of 10, 20, 30, 40, 50 and 60 gfd at 1500 psig with 3.5% salt water feeds. The feed water, obtained at the Azusa Water Reclamation Plant at the start of each day, was filtered through Whatman No. 5 filter paper and was acidified to pH 6.0 or less and maintained at that level throughout each test. The final feed water concentration reached during these operations was governed by the flux rate and mineral removal rate. At the lower fluxes encountered at 750 psig operating pressure, it was only possible to concentrate the feed water 7 to 12 fold. The operating data gathered during these tests as well as the product and feed water analyses are shown in Tables 5 through 11 and Figures 11 through 17. It is well to point out that the quality of product water was good throughout the tests despite the wide day to day variations in feed quality so characteristic of any waste treatment plant.

a. The 10 gfd Membrane (Test 21)

Test No. 21 was carried out using a 10 gfd membrane. During this test (Table 5) the feed water TDS was concentrated approximately ninefold and the product water analysis from this concentrated feed contained 80 ppm TDS, 21 ppm COD, and 0.1 ppm ABS. The composite product from the overall test was of high quality and contained more than 85% of the original feed.

The operating data are shown graphically in Figure 11. The initial average flux of 18.4 gfd fell to 12.8 gfd in six hours and the production rate of cell B, the second cell in series, was higher than that of cell A at the end of the test.

In this test and later tests, cell B showed a smaller flux reduction throughout the test than did cell A. This was true even when cell B was placed first in the flow path. This difference in cell performance is attributed to minor differences in cell geometry. The water flow gap in each cell was 0.010" ± 0.0002". Small differences in machined tolerances are probably reflected in cell performance.

The feed and product water analyses indicated that, as the product became more concentrated, the mineral removal fraction increased, while the percent COD removed decreased and increased again within narrow limits. The final feed contained approximately a ninefold concentration of TDS, a fivefold concentration of COD and a twofold concentration of ABS.

b. The 20 gfd Membrane (Test 23)

The results of the test with a 20 gfd membrane are presented in Table 6 and in Figure 12. The feed conductivity tabulation indicated the addition of more treatment plant effluent from time to time to the feed tank. This was done to increase the final feed concentration within the time constraints placed upon each test (24 hours); i. e., more dissolved minerals (in the form of feed water) were added in order that the final concentration result in high values for percentage of dissolved substance.

After 4-3/4 hours of test operation, the pressure regulating valve became faulty and allowed a pressure buildup which is reflected in the flux rise between 4-3/4 and 4-1/2 hours.

The product and feed water analyses showed greater than 98% TDS removal throughout the test and 90 - 96% COD removal. The final feed was concentrated 5.7 times with respect to TDS and 4 times with respect to COD. The composite product was again of high purity.

The average product flux dropped from 22.3 gfd to 18.3 gfd in 6-1/4 hours in cell B, whereas in cell A the initial flux was 27.4 gfd and the final flux was 13.8 gfd. At 3-1/2 hours, the flux rate from cell A dropped below the cell B product flux rate.

c. The 30 gfd Membrane (Test 24)

During this test, the feed water was concentrated approximately 13.7 times based upon conductivity measurements, and more feed was added during the test to enable a greater concentration of the final feed.

The operating data and water analyses are presented in Table 7 and in Figure 13. This film type removed as much as 97% of the total dissolved solids to an almost 14-fold concentration of the feed water. The films reduced the initial feed COD value by 65% and the final feed, containing 700 ppm COD, was reduced by 96%. During this test, the final product ABS level rose to only 0.6 ppm from 10.6 ppm in the feed.

The product flux rate dropped from the average initial value of 32.2 gfd to 14.3 gfd with feed water containing 7740 ppm of TDS.

d. The 40 gfd Membrane (Test 27)

The cell was operated for approximately 6-1/2 hours with the 40 gfd membrane type, the results being presented in Table 8 and in Figure 1r. The membrane removed 73% to 88% of the dissolved minerals up to 5.1 concentrations of TDS and 90% to 95% of the COD up to 2 concentrations of COD values.

The product flux fell from an average initial value of 36.2 gfd to 14.0 gfd at 5.1 concentrations of feed as measured by TDS.

e. The 50 gfd Membrane (Test 25)

The results of cell operation utilizing a 50 gfd film type are presented in Table 9 and in Figure 15. The feed water pH was adjusted at the start with hydrochloric acid and feed additions were made during the run. The feed water was concentrated about 10.2 times based upon TDS and 14 times based upon COD determinations. The films removed from 47% to 81% of the dissolved minerals and from 59% to 100% of the COD in feed water containing 600 ppm of COD. The apparent 100% removal must be questioned in the light of other tests on "tighter" membranes.

The product flux rate rose upon the addition of feed at 4 hours and 20 minutes, and then assumed the previously-established flux reduction rate. This would imply that the decrease in flux is not solely a function of feed concentration nor of time.

f. The 60 gfd Membrane (Tests 33 and 36)

Membranes which had been fabricated to represent the most open film type (i.e., about 50% salt retention and high flux rates) were tested in runs 33 and 36. In each case, the membrane performance was more nearly that of a 30-40 gfd type, and no further attempts were made to test the more open film type.

Test number 33 was completed within six hours (Table 10 and Figure 16). The final feed contained 5210 ppm of TDS which was almost a ninefold increase in the initial TDS concentration. The film exhibited a high contaminant removal capacity and the flux rate was similar to that of the 40 gfd type (Test 27). The composite product, representing renovation of 84% of the feed, had a composition of 34 ppm TDS, and 0.3 ppm ABS and 6.0 ppm COD.

Test number 36 (Table and Figure 17), a repeat evaluation of the 60 gfd membrane type, exhibited initial flux rates similar to that of a 20 gfd type. At the end of the run, the feed contained 8230 ppm TDS and the product flux was 17.6 and 14.5 gfd in the two cells. The final feed contained more than a fifteenfold increase in the initial TDS, a fivefold increase in the initial ABS and an eightfold increase in the initial COD. Almost 88% of the feed was recovered as composite product containing 127 ppm TDS, 0.3 ppm ABS and 12 ppm COD.

4. <u>The 1500 psig Test Series</u>

A series of tests was conducted at 1500 psig which paralleled the study at 750 psig. Attempts were made to obtain information concerning film longevity and performance at higher feed concentrations. Therefore, in some cases, the tests were continued into a second day by (a) blending fresh effluent into the concentrate remaining from the previous test to make a more concentrated waste water feed (Tests 31 and 32), (b) running a duplicate test the second day with the same films and fresh waste water (Test 37), (c) mounting a new film in one cell for the second day's operation (Test 30).

a. The 10 gfd Membrane (Test 31)

The 10 gfd film was tested in two stages (Table 12). Feed water was concentrated from 620 to greater than 2164 ppm TDS over a 5-1/2 hour period with removal of 73% of the feed as a product at average fluxes of 23.8 gfd dropping to 14.7 gfd. The test was then stopped and, prior to its resumption the following day, the concentrated feed water was blended with secondary filter effluent

obtained the second day. The initial composition the second day was 1418 ppm TDS, 8.5 ppm ABS and 153 ppm COD. This was then concentrated to 4146 ppm TDS, 17 ppm ABS and 325 ppm COD. The total product of the two-day tests (68.5% of the feed) contained less than 60 ppm TDS, less than 0.3 ppm ABS and less than 10 ppm of COD.

The graph of flux versus time shown in Figure 18 indicates that on the second day, the flux increased over the value prior to shutdown and again diminished as the test continued. This indicates that flux reduction is not the result of an irreversible change in the membrane.

b. The 20 gfd Membrane (Test 30)

The test of the 20 gfd film (Table 13) was also performed in two parts. The test was run utilizing one cell which concentrated the feed from 542 ppm TDS to 1350 ppm TDS with removal of 41.6% of the feed. The test was continued the following day with two cells, and the concentrated waste water feed was blended with fresh filtered effluent. The feed was concentrated from 986 ppm TDS to 6684 ppm TDS with removal of 80.8% of the feed (Figure 18). The total product obtained contained 42 ppm TDS, 0.2 ppm ABS and 14 ppm COD. The flux dropped from 32.8 gfd to 13.1 gfd in the one cell after approximately eight hours of operation (over a 36-hour period).

c. The 30 gfd Membrane (Test 28)

The 30 gfd membrane was tested over six hours (Table 3) with concentration of feed water from 595 ppm TDS to 6290 ppm TDS and removal of 83% of the feed as product. The final product blend contained 53 ppm TDS, 0.1 ppm ABS and 10 ppm COD. The average product flux (Figure 9) fell from 32.0 gfd to 11.6 gfd during the test. This test was also utilized as the basic feasibility test and has been reported earlier.

A portion of the product water obtained between 60 and 120 minutes of operation was submitted for mineral analysis; results are shown in Table 4. Solids accumulated upon the membrane surface were also analyzed and found to be 60% volatile at 600°C. The nonvolatile residue was predominantly iron. Thus, it is likely that the deposit consisted of an organic material deposit along with an oxide or bicarbonate of iron.

d. The 40 gfd Membrane (Test 29)

The 40 gfd membrane was tested in two parts (Table 14) following equipment difficulties during the first portion of the test. The feed was concentrated from 527 ppm TDS to 1765 ppm TDS with 64% recovery (Figure 20); on the second day, the same feed was concentrated from 1650 ppm TDS to 4650 ppm TDS. The product water for the initial four hours contained 30 ppm TDS, 0.2 ppm ABS and 10 ppm COD. During the following hours, an extremely rapid deterioration of the cell B film was observed. The plot of operating data shown in Figure 19 illustrates that, upon resumption of the test the next day, the film in cell B exhibited a high flux together with the low contaminant retention.

e. The 50 gfd Membrane (Test 37)

This test (Table 15) was completed within 5-1/2 hours with the recovery of 81% of the feed as composite product containing 47 ppm TDS, 0.2 ppm ABS and 9 ppm COD. The cell A test was started 70 minutes following the start of cell B and the Cell A flux (Figure 21) was found to drop rapidly to that of cell B. The cell was shut down overnight and the test was repeated on the following day using a new supply of filtered waste water containing 565 ppm TDS, 5 ppm ABS and 85 ppm COD. After two hours of operation, cell A leaked at the O-ring seal and was disconnected. In this test (Table 15), 76.6% of the feed water was recovered as product containing 48 ppm TDS, 0.2 ppm ABS and 6 ppm COD. The initial flux of 26.1 gfd (average) dropped to 13.0 gfd after six hours and an almost 7-fold increase in the feed water concentration (Figure 20) was achieved.

At the conclusion of the feasibility study, three tests were designed to characterize flux reduction problems. The tests consisted of (a) concentrating 1500 ppm sodium chloride solution over a six-hour period (Table 17 and Figure 24), (b) operating the unit 72 hours (Figure 25) continuously with three batches of trickling filter effluent decolorized with Nuchar Aqua A, (c) utilizing charcoal filtered, cation exchanged trickling filter effluent over a six-hour period (Figure 25).

The results are contradictory inasmuch as the sodium chloride brine concentration was not accompanied by flux reduction while neither of the trickling filter treatment procedures duplicated this result. The tests are reported for the sake of completeness, although the results appear unreliable in view of the more complete work reported in the following section.

5. Supplementary Tests

The purpose of this series of tests (with the apparatus modified for continuous operation)(Figure 7) was to evaluate separately the effects of time, pressure and water composition upon the membrane flux rate; in particular, the flux decay as it related to feed; e.g., 750 ppm salt water vs secondary effluent. In these tests the 20 gfd membrane type was used. The general procedure was to operate continuously, 24 hours per day, 7 days per week, changing the feed water each working day.

a. Deionized Water Feed Followed by 0.075% Sodium Chloride Solution

In this, the first test of the series (Tables 19, 20 and Figure 26), the films operated at 750 psi with deionized water. Overnight, cell A developed a leak at the O-ring seal. This mechanical difficulty was repaired and the next day a new membrane was mounted in the cell. Consequently, the readings taken on any given day represented 24 hours longer exposure on cell B than on cell A. Referring to Figure 26, the 24-hour lead of cell B provides a means of separating system effects (pressure and salinity variations) from other effects. For example, a system pressure increase is manifested in the figure as two pips out of phase by 24 hours. This is illustrated at 3-2/3 days on Curve A and 4-2/3 days on Curve B. Discounting these system effects, the curves in Figure 26 were drawn and are the basis of the following discussion.

From the appearance of the test results, the film performance may be divided into at least two segments, (1) the initial period of rapid flux decline which is followed by (2) a levelled-off period of almost constant flux rate. In both cells, the initial film flux diminished by 15 - 16 % within five days. It thus becomes clear that in evaluating film performance it is necessary to distinguish between the initial film flux (at time = 0) and the value following several days' operation (the flattened portion of the curve).

The test was continued through the fourteenth day with deionized water feed and the flux during this period dropped approximately 0.02 and 0.06 gfd per day. With the substitution of 750 ppm salt water the flux again dropped within 24 hours to a new level which again flattened out at a lower value. It is

unclear at this point what caused this second flux decline. There was a reduction in the effective pressure of the system by at least the osmotic pressure of the 750 ppm salt solution. This pressure may be calculated from the classical equation $\pi = n RT$ and is found to be 9.2 psi. Inasmuch as the flux drop of 1.6 gfd and 1.7 gfd (5.3% and 5.8%) would correspond to an effective pressure reduction of 40 and 45 psi, the change in osmotic pressure is not the total cause of this flux decline. However, the flow of salt-free water through the membrane increases the salt concentration at the salt water membrane interface. The extent of the boundary layer concentration increase is presently being investigated in these laboratories and may be as great as five times the bulk concentration*.

It thus appears that the greater portion of the second flux drop in this test may be attributed to diminished effective pressure resulting from increased boundary layer concentrations. That this is not the complete answer is evident from two facts: (1) the 24-hour delay in establishing the boundary layer and (2) the slope of flux vs time for 750 ppm water compared to that for deionized water. With 750 ppm, the initial flux decline was between 0.13 and 0.25 gfd per day.

This test definitely has established that the membrane flux drops sharply during the first few days of operation. It was concluded that further testing should proceed only with flux stabilized membranes.

b. Waste Water Test with a Conditioned Membrane

The purpose of this test (Table 21, Figure 27) was to compare the flux decay of membranes observed with 750 ppm saline feed water with that resulting from the use of secondary effluent feed. A conditioned membrane has been defined as one which has been in operation sufficiently long to have achieved a constant flux rate. During this test a high pressure filter was in use between the inlet pressure gage and the first cell in the flow path. The filter was cleaned daily; nonetheless, it developed pressure drops of 400 - 800 psi. The wide variation of flux measurements during the initial period is in part attributed to the constant depressurization by virtue of removing and reinstalling the filter element. The filter was removed from the system following nine days' operation. The initial flux

* C. R. Wunderlich - unpublished results.

values of 34.9 and 32.0 gfd with 750 ppm feed fell by 20% and 18% to 28.0 and 27.0 gfd during the conditioning period.

The waste water utilized in the remaining portion of the test was trickling filter effluent obtained daily from the Azusa Water Reclamation Plant. One hundred and fifty liters of this effluent was filtered through glass cloth filter media (No. 1106 BH, Mine Safety Appliance, Pittsburgh) followed by acidification with sulphuric acid. With the substitution of waste water feed for the saline solution of approximately equivalent concentration, the flux underwent a rapid drop during the first 48 hours (11th day) to about 15.9 and 12.0 gfd, a drop of 43% and 55%. During the following five days' operation, the production rate dropped further to 12.2 and 9.3 gfd.

During this and subsequent tests, samples of the feed, product and reject stream were withdrawn, acidified to pH 2 and forwarded for organic carbon analysis to the Robert A. Taft Sanitary Engineering Center. These results are listed in Table 21. The analyses indicated that the feed contained from 17.5 to 20.0 mg/l of carbon and the product from < 1.0 to 3.5 mg/l. The average value for the six product water analyses was 1.7 mg/l. The three analyses of the reject stream varied from 15.5 to 21.5 mg/l. In two cases the reject was lower in carbon than the feed. This result is attributed to the film holding tank, through which the reject stream passed on its way to the storage tank. This film holding tank behaved as a miniature settling basin. Following cell disassembly, a deposit was again observed on the membrane. This deposit was analyzed (as were deposits of earlier and later tests) and its nature is discussed in another section of this report.

The analytical tests confirmed the excellent quality of the reverse osmosis product water which had been indicated earlier in the COD analysis. Furthermore, the test indicated that this trickling filter effluent shows unique effects upon the flux rate. Thus it appears that the application of reverse osmosis for waste water renovation may require pretreatment of the effluent.

c. Membrane Test with Treated Waste Water

The purpose of this test was to determine whether a pre-treatment could be devised which would eliminate the cause of the rapid flux decay

experienced during reverse osmosis experiments with secondary effluent. The performance with treated waste water could then be compared against performance with 750 ppm sodium chloride solution to determine the feasibility of the waste water treatment process.

For this laboratory test, a simple batchwise treatment was used which incorporated a flocculating agent to reduce turbidity and activated carbon to reduce organic contamination. Several flocculants and combinations of flocculants and carbons were screened in a modified "jar test" program. The flocculant was added to 500 ml of waste water in an 800 ml beaker; the pH was adjusted where necessary with 0.10N sulfuric acid, the mixture was stirred two minutes and then allowed to settle for 24 hours. The mixture was then filtered through Whatman No. 5 filter paper and the turbidity of the filtrate was measured by the light absorbed at 670 mμ compared with a distilled water blank in a Bausch and Lomb Spectronic 20 Colorimeter. These screening tests indicated that 100% transmission was obtained when the feed was treated by either of two methods: (1) a combination of aluminum sulphate, sodium meta-silicate and activated carbon or (2) ferric chloride plus activated carbon. It was decided to utilize the first of these two mixtures. The feed treatment consisted of adding, to 98 liters of trickling filter effluent, a two liter solution of waste water containing 58 g $Al_2(SO_4)_3 \cdot 18\ H_2O$ and 5.87 g $Na_2SiO_3 \cdot 9\ H_2O$. The mixture was agitated for two hours at 50 rpm whereupon 40 grams of activated carbon (Nuchar C-190 N) was added while stirring rapidly. The stirrer speed was dropped to 50 rpm when the carbon was fully dispersed and stirring was continued for 10 additional hours. The mixture was allowed to settle for eight hours and was then filtered under vacuum through Whatman No. 5 paper. The clear filtrate was acidified with 10.0N sulfuric acid and was utilized as feed stock. The feed was changed daily, except on weekends.

The 20 gfd membrane was conditioned for six days with 750 ppm sodium chloride solution. During this period the flux dropped from 36.8 and 34.7 gfd to 28.5 and 27.0 gfd (approximately 23% and 22%) while the product salt concentration measured 64 ppm initially and 43 ppm after stabilization, a product improvement of 33%. With the addition of treated waste water on the sixth day,

the flux dropped within 24 hours to 25.7 and 24.7 gfd (avg. 7.5%) with a corresponding improvement in product concentration from 43 ppm to 15 ppm. This product quality improvement with addition of the treated waste water is more striking when viewed in terms of salt rejection. The last reading with sodium chloride feed indicated 94.5% salt rejection which improved to 97.1% with waste water feed.

The test was continued through the 18th day with seven changes of treated effluent. Membrane performance varied slightly with each feed water change. The cell B flux started to rise sharply on the 14th day with corresponding wide variations in product water conductivity. Cell A continued to perform well until the 17th day when there was an increase in product conductivity. (Examination of both films at the end (7th test) showed 1/8" tears in the film opposite each water inlet and in cell B there was an additional 1" cut at the O-ring seal.)

The feed water change-over on the 18th day had not been carbon treated but only contacted with the flocculating agents. This feed was utilized through the 24th day with a sharp decrease in flux within 24 hours from 25.7 to 22.0 gfd and continued decrease to a value of 19.7 gfd.

D. DISCUSSION OF RESULTS

1. Product Quality

Throughout virtually the entire study, the feed and product water mineral contents were determined by TDS analysis. In two cases, Tests 18 and 28, more complete mineral analyses were performed and the results are presented in Table 4; these results indicate 97% to 99% reduction. The analyses further indicate that with the exception of chloride ion, the mineral content reduction is generally in the 90% to 100% range. The mineral analyses of these samples and the composite products (Table 16) prove the water to be of a high quality. No bacteriological or viral examinations of the product water were made during this initial feasibility study. However, prior tests in the Aerojet laboratories had shown that selected bacteria and viruses were removed during reverse osmosis; thus, it is likely that the product was also of high quality with respect to micro-organism contamination.

The initial feed contained 2.7-6.0 ppm of ABS and the composite product (Table 16) in most cases showed less than 0.3 ppm ABS even though the ABS was concentrated to 28.2 ppm in one case. With respect to ABS content, the product is well within the target of less than 0.5 ppm of ABS.

In considering the re-use of waste water for human consumption, it is necessary to establish safe limits for dissolved contaminants. Indeed, it would be desirable to have such standards for tap water presently in use. Present criteria for drinking water generally involve only mineral content for which a safe limit of 500 ppm of total dissolved inorganic solid has been established. However, it has been necessary to modify this criterion by specifying acceptable upper limits for specific contaminant species, of which boron is a notable example.

The U. S. Public Health Service is now pursuing the vital task of establishing the safe organic content for water to be used for human consumption. The first task would appear to be to establish an overall criterion for organic contaminants similar to the TDS parameter which often is used for mineral constituents. Of course, TDS includes organic materials which only points up the need for improved definition. The carbon tetrachloride extraction criterion is recognized to be an inadequate test.

The problem of defining organic constituents is a difficult one because of the great variety of these materials which may be encountered in waste water. Perhaps the best overall criterion for organic contaminants is the determination of weight loss upon ignition, despite the disadvantage that bicarbonates, carbonates, ammonium salts and certain metallic halides are volatile at high temperatures. However, the most important disadvantage is probably that the determination is cumbersome. Other tests which are often used are the chemical oxygen demand (COD) and biological oxygen demand (BOD) which obviously do not measure organic materials that are refractory under the test conditions, of which there are many.

It is then clear that the problem of establishing an overall criterion for potability with respect to organic contamination is extremely difficult and has not been completed. Even if COD is considered an acceptable criterion, safe

upper limits for potability have not been established. Furthermore, it will be necessary to establish safe limits for an untold number of individual contaminants, which may be tolerable only in much lower concentrations than most other organic constituents of drinking water.

The authors of this report and the sponsors of the program are vitally interested in the re-use of waste water for human consumption. The feasibility study covered by this report was conducted with such a goal in mind. For the purposes of carrying out this study, the Public Health Service established a set of reasonable tragets for product quality which were <10 ppm COD and <0.5 ppm ABS. These targets were agreed upon, without intimation that they represented criteria for potability, especially with regard to COD and ABS. In the work reported herein, the targets established by the contracting agency were met in all respects. Furthermore, it is believed that the product quality is better than that which would be provided by any other process under comparable conditions of application. Those membranes tailored for lower flux did not, in general, change the concentration of dissolved contaminants in the product, and the flux differences were truly not startling. The success achieved with product quality at the lower pressure (750 psi) is most encouraging since operation at this lower pressure would markedly improve process economics. Indeed, it would appear that still lower operating pressures are quite feasible, but the determination of minimum operating pressure must remain for a later study.

2. Product Flux

The production rate, measured in gallons per square foot of membrane surface per day (gfd) is dependent upon the applied pressure, the feed water osmotic pressure at the boundary layer (which varies directly with dissolved solids concentration), and upon the membrane characteristics. One objective of the study reported herein was to determine the specific effects of dilute and concentrated waste water upon the membrane flux. The initial tests were therefore designed to recirculate the feed and thus to concentrate the waste water.

From the test data reported (Tables 1 through 16), it may be seen that product flux drops as each test progresses and the feed water concentration

increases. The data have been summarized in Figures 21 and 22 which are plots of the flux at various feed water concentrations. From the data of the 750 psig series (Figure 21) it would appear that a minimal initial difference occurs in film performance at this pressure and, further, that the various membrane types achieve similar flux values at the higher feed water concentrations. It should be noted that approximately 75% of the feed is renovated during the first threefold feed water concentrations and that, in extrapolating the results to a realistic situation, the fluxes at low feed water concentrations are most significant in determining the average process flux. It is also noteworthy that the feed concentration increases with time, and at least part of the flux decrease is attributable solely to flux-concentration variation. However, a significant portion of the initial drop cannot be so explained.

From the 1500 psig test series (Figure 22), it may be seen that greater initial flux differences occur at the higher pressure (flux is from 26 to 42 gfd) but that the fluxes for the different film types also reach similar values with the progression of the various tests.

It is interesting that the tighter membranes (Tests 21 and 23) exhibited the least degradation. Part of the flux decrease is believed to derive from compaction of the membrane resulting from plastic flow of the swollen polymer under pressure. On the other hand, the rate of decrease in flux is found to be considerably greater in the case of secondary effluent than is observed under similar conditions for saline water of comparable TDS. Thus, a major portion of the decrease is likely to be attributable to some constituent of secondary effluent, possibly the colloidal proteins known to be present. Coupled with the outstanding product quality, the initial fluxes observed throughout the various tests point to reverse osmosis as a most promising waste water renovation procecess. The dropoff in flux observed after a relatively short time tends to detract from the outstanding attractiveness of the process, although even the lower fluxes would be useful.

It should be pointed out that the average recoveries of some 80-85% of the feed are not representative of process limitations, but were rather the result of experimental conditions where the volume of samples represented 15-25% of the feed volume. Indeed, in one test, 95% of the feed was recovered and a minimum of 98% recovery is considered probable.

Three tests were undertaken at the conclusion of the feasibility study to gain insight into the causes of flux reduction. The sodium chloride brine concentration test (Table 17, Figure 24) indicated that over a six hour period a lesser flux reduction occurred with sodium chloride brine than with trickling filter effluent.

The continuously operated tests described under C.5 in this section evaluated pressure-time effects upon the membrane parameters. The unit was operated up to four weeks without concentrating feed during the tests. The results of these tests show the initial flux decreases sharply during the first 5 - 7 days until a leveled off value is achieved which declined only slightly during the remainder of the test period.

Four feed types were selected: (1) deionized water, (2) 750 ppm sodium chloride solution, (3) filtered waste water and (4) treated waste water. In the test with deionized feed the flux leveled off 15 - 16% below the initial values. From there on, the decline rate was 0.02 and 0.06 gfd/day with deionized water. Thereafter, 750 ppm sodium chloride solution was used during the membrane conditioning period and flux declined 18 - 23% from the initial values. Now, having available membranes with a fairly constant flux rate, it was possible to substitute trickling filter effluent as feed and to observe the specific effects of waste water similar to that which was used during the earlier concentration studies. The established flux values of 28 and 27 GFD dropped within 48 hours to 15.9 and 12.0 gfd, where the flux-time curve appears to level off slightly. The membrane flux continued to decline and, following seven days' exposure to waste water, the flux had declined 4.7% per day. Clearly the waste water composition altered the membrane performance such that it differed considerably from sodium chloride solutions of similar TDS.

Two conclusions have been reached: (1) there is a 15-25% flux decline during the first days of operation followed by a constant performance characteristic, and (2) the trickling filter effluent causes a more accelerated flux reduction than sodium chloride solution. In terms of the earlier waste water concentration tests, it is apparent that the results were confounded by (1) the use of membranes without prior conditioning and (2) the concentrating effects of the trickling filter effluent.

In the third test of this series, it was demonstrated that it is possible to devise a treatment for the trickling filter effluent which eliminated at least partly the contaminants which had caused flux decline. In effect, the flocculated, carbon treated effluent was equivalent to sodium chloride solutions of similar TDS. During this test, the salt permeation rose during the 14th and 17th days and at the completion of the tests, tears were observed in each membrane. If we assume that the tears occurred during the 14th and 17th days, an anomaly becomes apparent since the product conductivity did not remain at a consistently high level but varied as much as 100% in each cell. This possibly indicates that the flow through these membrane holes was not constant, or alternately that a desalination film was deposited in situ.

The following conclusions concerning film flux have been reached.

a. Films having high initial flux rates (30 to 50 gfd) exhibit decreases in the flux rate from 1/3 to 1/2 that of the initial rate within several hours; the decline is both time-related and feed concentration related.

b. Films having lower initial flux rates exhibit a considerably lesser degree of flux decrease and in some cases virtually none at all.

c. The initial film flux rate which is determined in part by film fabrication techniques, changes as the feed concentration increases, and tends to equilibrate.

d. The flux drop during the concentration tests appears to have been the result of (1) initial pressure effects which were in progress during the test interval, (2) the concentration of flux diminishing elements contained in trickling filter effluent.

e. Trickling filter effluent when treated for turbidity and organic carbon reduction yields a membrane performance equivalent to a sodium chloride brine of similar TDS.

IV. SIMULATED LONGEVITY TESTS

Two sets of films were immersed in the secondary effluent line at the Azusa Water Reclamation Plant. The films deteriorated rapidly over a thirty-day interval which coincided with a heavy midge larvae infestation at the Reclamation Plant. These films, when treated at 1500 psig with synthetic sewage (about 2000 ppm TDS), exhibited no salt retention capability and had fluxes greater than 500 gfd.

Another set of films, tested at 1500 psig with synthetic sewage, exhibited values of:

15.1 gfd and 40 µmhos conductivity - initial
14.7 gfd and 40 µmhos conductivity after one day exposure
15.7 gfd and 60 µmhos conductivity after nine day exposure
11.4 gfd and 55 µmhos conductivity after thirty day exposure

Salt retention remained good although flux diminished somewhat. In addition, the physical properties of Shore hardness, tear strength and tensile strength were determined. The variations within each sample category were greater than the variations caused by exposure; thus, no trend could be observed. The film's physical characteristics varied as follows:

Tear strength	13-500 pounds/inch thickness
Tensile strength	300-1100 pounds/sq.in.
Shore "D" hardness	12-30

The results indicated that cellulose acetate membranes may be attacked by elements present in waste water. The evidence suggests biological attack, as this was the most striking difference at the test site between the two test periods. It is also of interest that with the onset of cool weather, there appeared to be diminished biological activity and the later set of films, used during the cool period, have proven to be more durable than the previous ones.

A third test was established during the two month interval that the cell system was operated continuously. Several 20 gfd membranes were placed in a covered holding tank, through which the concentrated reject stream flowed. The films were exposed to acidified (a) sodium chloride (ca 900 ppm) (b) filtered waste water and (c) treated waste water. Portions of the films were removed and tested at intervals on another reverse osmosis test apparatus (2-1/2 hours at 1500 psi with 3-1/2% sodium chloride solution).

The results are tabulated in Table 23. The test average shows a steady but slight membrane deterioration. During the 63-day exposure, the flux increased by 23% (from 18.9 to 21.9 gfd) and product salt content has increased by 25% (from 935 to 1165 ppm).

This test indicates that, upon exposure to flowing waste water or sodium chloride brine at atmospheric pressure, the membrane effectiveness has decreased 23-25% in sixty days.

V. ECONOMIC EVALUATIONS

The present limited study, having produced acceptable low mineral content water from secondary treatment plant effluent, has demonstrated the technical feasibility of reverse osmosis as a waste water renovation practice.

The study has resulted in a process which should be subject to pre-pilot plant scaleup immediately while minor difficulties encountered are being overcome through additional laboratory research and development. To illustrate the great promise of the process, a preliminary cost estimate was prepared. In order to make the estimate realistic, it was necessary to make assumptions relative to the degree of success which can reasonably be expected in overcoming the technical challenge.

In making the estimate, it was assumed that feed composition would be similar to that used in this study and that COD requirements will limit product recovery to 90%. This is an extremely conservative assumption, but was used to ensure that the estimate would be applicable to all grades of secondary effluent. The calculated product composition was less than 70 ppm TDS, less than 0.3 ppm ABS and less than 10 ppm COD (approximately the product composite analysis derived in this study).

The plant would operate at 750 psig with an average flux of 24 gfd, somewhat greater (26%) than the average fluxes achieved by the most successful membranes used in the concentration study. A membrane life of 5-1/2 months has been assumed, based upon the lifetimes demonstrated in brackish water studies. The estimated plant cost was based upon scaling up of the present 100 sq ft reverse osmosis desalination apparatus to 30,000 sq ft modules.

The cost estimating procedure utilized (Appendix A) is that adopted by the Office of Saline Water, Department of the Interior. By this procedure it is estimated that a plant producing 10,000,000 gallons per day will require a capital investment of $3,143,000 and that the cost of the renovated product will be 24.9 cents per 1000 gallons, including amortization of capital investment.

VI. CONCLUSIONS AND RECOMMENDATIONS

In these initial feasibility studies, the single most striking achievement of waste water renovation by reverse osmosis was the high quality product obtained. Product water containing less than 50 ppm TDS and 10 ppm or less of COD was produced while concentrating trickling filter effluent twelve times from 595 to 7185 ppm TDS. This consistent low mineral and low organic content product coupled with the known low energy expenditure emphasizes the high potential of reverse osmosis for waste water renovation.

The product flux data reported for the initial concentration tests are somewhat confusing. During the concentration cycle, the membrane flux rates for the more open type films approached the performance of the tighter films. This flux degradation may have been partly due to collapse of the membrane gel structure and partly due to some constituent of the feed. The isolation of the factors responsible for flux reduction proved extremely difficult within the limitations of the feasibility program, where it was impossible to isolate the effects of time, pressure and increasing waste water concentration.

Subsequent tests of 15-25 days' duration with continuous operation indicated that (1) film compaction drops the flux rating from 15-25% within 5-7 days, (2) the flux then declines continuously at a nearly constant rate, (3) trickling filter effluent considerably diminishes the constant flux rate (almost 5% per day), and (4) trickling filter effluent which has been treated to reduce turbidity and organic contamination performs similarly to brines.

The additional value of these few tests, following the feasibility study, strongly indicated the potential of this reverse osmosis application. The results have been extremely encouraging and future work should be designed to further the development of the process as well as to overcome the problems encountered. It is thus recommended that a program continuation be carried out in a test apparatus capable of removing as much of the feed as desired (as purified product) in a single pass through the apparatus. The modified equipment would not then require recycle of the feed stream. In this manner, a steady state can be established quickly in the test and effects of feed water variations can be determined quickly.

The minimum unit which can be built to yield 98% renovation in a single pass would be approximately 200 gallons/day in capacity. The size is fixed by minimum flow path and flow gap requirements. The construction of such a unit would have several advantages in addition to that of enabling more useful experiments to be carried out. Successful completion of a series of experiments on such a unit would constitute the first of a series of scale-ups which could culminate in a plant of useful size. Furthermore, upon completion of the series of exploratory experiments, the unit could be transported to a municipal waste treatment plant, where relatively long term operation could be undertaken to demonstrate the feasibility of the process under realistic conditions.

The continuation program would include the following:

1. Design of a single-pass waste water renovation installation with a nominal capacity of 200 gal/day.

2. Fabrication, assembly and checkout operations of the unit in the laboratories at Aerojet's Von Karman Center.

3. Maximization of product water flux rates on waste water feed through development of improved membranes and water treatment processes.

4. Maximization of membrane life exposed to waste water feed.

5. Operation of the unit at the Azusa Waste Water Reclamation Plant under typical on-site operating conditions for a period of six months, including a longevity test of at least thirty day's duration.

The support of such a program by the Public Health Service as a logical follow-on to the feasibility study is respectfully urged.

TABLE 1

PRELIMINARY TEST - WASTE WATER RENOVATION

Test No. 15; Pressure - 1500 psig; Film No. 10-2-B4, 10-2-B6

Feed - Filtered Effluent from Azusa Water Reclamation Plant

Time mins	Water Removed as Product % of Feed	Feed Analyses			Product Analyses			Product Flux gfd
		Conductivity μmho/cm	TDS ppm	COD ppm	Conductivity μmho/cm	TDS ppm	COD ppm	
0		950	590	79	60	14	3	16.9
30	9.7	1,200			50			14.0
40	15.1	1,250			55			12.5
75	19.7	1,400			60			6.0
90	22.6	1,450			62			6.0
120	26.4	1,450	725	115	70	18	5	5.5
150	29.8	1,550	845	118	65	17	6	5.0
180	32.8	1,600			70			4.5
210	35.6	1,700			80			4.2
240	37.8	1,800			80			4.0
265	39.8	2,500			260			15.8
285	47.6	2,500			300	85		16.8
305	55.3	3,500	2,530		280	123		17.2

TABLE 2

BASIC FEASIBILITY DETERMINATION

(Step 1, Part A of Work Statement)

Test No. 18; Pressure - 1500 psig; Film No. 10-7-B5, 10-7-B7

Feed - Filtered Effluent from Azusa Water Reclamation Plant

Time mins.	Water Removed as Product % of Feed	Feed Analyses				Product Analyses				Product Flux gfd
		Conductivity μmho/cm	TDS ppm	ABS ppm	COD ppm	Conductivity μmho/cm	TDS ppm	ABS ppm	COD ppm	
0		875	501	3.6	81					
15[1]	3.6	875				< 40				25.5
30[1]	5.1	1,000				< 40	6	0.1	2	21.0
60	9.4	1,000				< 40				12.0
100	14.0	1,100	710	4.0	600	75				32.0
110	20.2	1,150				85				30.0
120	23.4	1,150				85				30.0
135[1]	23.6	1,225				90				29.0
150	26.5	1,200				80				28.0
165	29.2	1,350				85				27.0
180	28.8	1,350				90				26.0
195	31.7	1,400				80				25.0
210	33.9	1,400				90				24.0
230	37.0	1,500				100				23.0
250	39.5	1,600				100				23.0
260	42.2	1,650				105				19.0
300	44.6	1,700				105				19.0
315	46.8	1,800				110				26.0

Table 2 (continued)

Time mins.	Water Removed as Product % of Feed	Feed Analyses				Product Analyses				Product Flux gfd
		Conductivity μmho/cm	TDS ppm	ABS ppm	COD ppm	Conductivity μmho/cm	TDS ppm	ABS ppm	COD ppm	
335	49.7	1,875				100				19.0
360	52.2	2,000	1,200	5.0	>975[3]	125	36	0	>93[3]	18.0
385	54.9	2,100				130				17.0
410	57.4	2,200				140				17.0
425	59.2	2,300				145				17.0
445	62.3	2,400				160				16.0
470	63.6	2,700				170				15.0
490	65.5	2,800				180				15.0
510	67.5	3,000				185				15.0
530	69.0	3,000	1,980	6.4	>975[3]	185	48	0	>93[3]	15.0
530[2]		2,950				—				
540	69.6	2,950				250				
555	70.9	3,200				210				21.0
570	71.6	3,500				190				20.0
585	72.6	4,000				200				19.0
600	73.5	4,000				200				18.0
615	74.6	4,100				200				18.0
635	75.7	4,500				220				18.0
650[4]	76.7	4,900				220				17.0
665	77.6	5,000				220				23.0
680	79.0	6,000				220				22.0
695	80.0	6,500				230				22.0
710	81.0	7,000	5,230			240				21.0

Table 2 (continued)

Note: After 75 minutes, feed water pH was adjusted with acetic acid 5.4 and maintained there for the remainder of the test by periodic addition of acid.

1 Feed diluted with addition of filtered secondary effluent.

2 Test shutdown overnight and resumed following morning.

3 Analysis believed to be faulty.

4 Test interrupted for one hour.

TABLE 3

BASIC FEASIBILITY DETERMINATION[1]

Test No. 28; Pressure - 1500 psig; Film No. 10-31-B9, 10-31-B10

Feed - Filtered Effluent from Azusa Water Reclamation Plant

Time mins.	Water Removed as Product % of Feed	Feed Analyses				Product Analyses				Product Flux[2] gfd
		Conductivity µmho/cm	TDS ppm	ABS ppm	COD ppm	Conductivity[2] µmho/cm	TDS ppm	ABS ppm	COD ppm	
0[3]		860	595	5.0	110					
15						50/238				
30[3]	12.1	1,250				50/147	79	0.2	11.5	30.6/33.4
45	18.8	1,350				50/122				27.6/30.1
60	25.1	1,520				51/128				25.3/28.8
75	31.2	1,720				50/120				24.6/26.2
90	36.8	1,890	1,145	5.5	145	50/92	28	0.1	5.9	23.0/25.3
105[3]	42.5	2,180				51/100				23.0/26.0
120	47.4	2,380				54/113				19.5/22.0
140	53.5	2,630				54/113				18.3/20.4
160	59.0	3,120				60/125				16.9/18.7
180	64.4	3,850				66/119				16.7/18.5
200[4]	56.5	4,350	2,620	8.8	225	77/139	45	0.1	12.2	15.3/16.7
220	60.4	2,940				68/104				14.3/15.8
240	64.0	3,450				68/108				14.0/16.1

Table 3 (continued)

Time mins.	Water Removed as Product % of Feed	Feed Analyses Conductivity µmho/cm	Feed Analyses TDS ppm	Feed Analyses ABS ppm	Feed Analyses COD ppm	Product Analyses Conductivity[2] µmho/cm	Product Analyses TDS ppm	Product Analyses ABS ppm	Product Analyses COD ppm	Product Flux[2] gfd
260	67.6	4,160				74/122				13.6/14.9
280	71.2	4,760				74/131				13.2/14.5
300	74.5	5,550				100/193				12.7/14.2
320	77.8	6,750	3,650	10.5	340	114/222	76	0.2	10.0	12.3/13.4
340	80.8	8,330				143/232				11.6/12.8
355	83.0	11,000	6,290	17.6	500	192/416	94	0.1	15.5	11.0/12.3

1 This test also serves as part of the membrane evaluation as required in Step 4, Part A of the Work Statement. The film used is a nominal 30 gfd one, operated at 1500 psig.

2 The two values given for product conductivity and product flux are the separate values measured at each cell. Other analyses are of the composite product obtained at the designated time. First cell in flow path is Cell A.

3 Added hydrochloric acid to feed water.

4 Food diluted with addition of filtered secondary effluent.

TABLE 4

WATER MINERAL ANALYSIS

	Feed Water (Typical) ppm	Product (Test 18) ppm	Product (Test 28) ppm
TDS	550	15	28
ABS	4.5	0.1	0.1
COD	95	2	6.0
pH	5[1]	6.3	5.5
Cations			
Na^{+}	85	4.6	6.1
K^{++}	40	4.9	2.7
NH_4^{+}	25	0	3.9
Ca^{++}	125	0	2.6
Mg^{++}	50	0.7	0
Fe^{++}	N. D.	0	0
Anions			
Cl^{-}	65	20.3	22.1
NO_3^{-}	2	0	0
HCO_3^{-}	260	8.1	3.5
$CO_3^{=}$	0	0	0
$SO_4^{=}$	200	1.7	3.3
$SiO_3^{=}$	30	2.9	2.9
$PO_4^{=}$ (total)	25	0	0

N.D. - not determined

[1] pH adjusted during test

TABLE 5

MEMBRANE EVALUATION - 10 GFD TYPE

(Step 2, Part A of Work Statement)

Test No. 21; Pressure - 720 psig; Film No. 10-16-B16, 10-16-B18

Feed - Filtered Effluent from Azusa Water Reclamation Plant

Time mins.	Water Removed as Product % of Feed	Feed Analyses				Product Analyses				Product Flux[1] gfd
		Conductivity µmho/cm	TDS ppm	ABS ppm	COD ppm	Conductivity[1] µmho/cm	TDS ppm	ABS ppm	COD ppm	
0[2]	5.4	910	825	2.9	130		61	0.1	1.5	
20[2]	10.2	1,220				61/91				18.8/18.0
40	15.0	1,220				43/65				19.8/19.0
60	20.1	1,660				42/60				19.1/18.3
80	25.2	1,430	910	3.7	140	74/74	53	0.1	4.2	18.4/17.4
100	30.5	1,500				60/87				19.0/18.4
120[2]	35.6	1,750				40/65				19.8/18.1
140	40.6	2,000				40/59				18.8/18.5
160	45.8	2,200				41/72				18.4/18.4
180	51.2	2,500				44/63				16.6/16.6
200	55.8	2,300				44/56				17.5/18.4
220	60.0	3,130				48/80				16.9/18.2
240	64.7	3,200				50/91				16.2/17.6
260	69.2	3,560				60/102				16.2/18.4

Table 5 (continued)

Time Mins.	Water Removed as Product % of Feed	Feed Analyses				Product Analyses				Product Flux[1] gfd
		Conductivity µmho/cm	TDS ppm	ABS ppm	COD ppm	Conductivity[1] µmho/cm	TDS ppm	ABS ppm	COD ppm	
280	73.8	4,160	1,255	3.8	165	69/115	47	0.1	13	15.4/18.4
300	78.2	5,250				66/130				15.6/18.4
320	82.4	6,600				100/165				14.0/17.4
340	85.0	9,100	2,375	5.1	310	220/145	48	0.1	17	13.6/17.2
355		11,600	7,515	5.4	670	200/310	80	0.1	21	11.3/14.3

[1]The two values given for product conductivity and product flux are the separate values measured at each cell. Other analyses were carried out on a composite product from the two cells at the designated time. First cell in flow path is Cell A.

[2]Hydrochloric acid added to feed.

TABLE 6

MEMBRANE EVALUATION - 20 GFD TYPE

(Step 3, Part A of Work Statement)

Test No. 23; Pressure - 750 psig; Film No. 10-16-B10, 10-17-B1

Feed - Filtered Effluent from Azusa Reclamation Plant

Time mins.	Water Removed as Product % of Feed	Feed Analyses				Product Analyses				Product Flux[1] gfd
		Conductivity μmho/cm	TDS ppm	ABS ppm	COD ppm	Conductivity[1] μmho/cm	TDS ppm	ABS ppm	COD ppm	
0[2]		830								
30	5.9	1,160	930	4.3	112	80/111	15	0.2	10	27.4/22.3
45[2]	11.8	1,250				70/95				27.0/21.6
60	17.6	1,790				71/73				26.8/21.9
75	23.6	2,090				61/81				26.0/22.2
90	29.3	2,220				65/84				25.8/21.6
105[3]	35.4	2,440	1,260	4.3	123	67/83	17	0.1	6.3	27.5/23.5
120	33.3	1,600				50/57				26.0/22.4
150	42.4	2,300				57/67				23.5/22.6
180[3]	51.2	3,530				66/85				23.7/22.8
210	50.0	2,630				63/73				21.6/22.4
240	56.7	3,130				70/82				19.5/20.6
260[2]	60.6	3,450				76/87				19.3/21.4
280	65.0	4,350				110/120				18.2/20.6
290[4]	67.4	4,880	2,610	5.7	227	150/170	20	0.1	11.7	27.0/24.0

Table 6 (continued)

Time mins.	Water Removed as Product % of Feed	Feed Analyses: Conductivity μmho/cm	Feed Analyses: TDS ppm	Feed Analyses: ABS ppm	Feed Analyses: COD ppm	Product Analyses: Conductivity[1] μmho/cm	Product Analyses: TDS ppm	Product Analyses: ABS ppm	Product Analyses: COD ppm	Product Flux[1] gfd
310	71.3	5,500				170/193				16.1/19.8
330	75.0	6,660				225/225				15.3/18.5
350	77.5	8,340				290/290				14.7/17.6
365	81.1	10,000	5,315	6.8	451	385/385	73	0.1	18.0	
375	82.7	11,900				500/476				13.6/18.3

[1]The two values given for product conductivity and product flux are the separate values measured at each cell. Other analyses were carried out on a composite product from the two cells at the designated time. First cell in flow path is Cell A.

[2]Acid added to feed water to adjust pH

[3]Feed diluted with addition of filtered secondary effluent.

[4]Operating pressure rose above 750 psig with concomitant flux rise.

TABLE 7

MEMBRANE EVALUATION - 30 GFD TYPE

(Step 3, Part A of Work Statement)

Test No. 24; Pressure - 750 psig; Film No. 10-22-B2, 10-22-B3

Feed - Filtered Effluent from Azusa Water Reclamation Plant

Time mins.	Water Removed as Product % of Feed	Feed Analyses				Product Analyses				Product Flux[1]
		Conductivity µmho/cm	TDS ppm	ABS ppm	COD ppm	Conductivity[1] µmho/cm	TDS ppm	ABS ppm	COD ppm	gfd
0[2]	0	910	560	3.0	88	83	43	0.2	33	
30[2]	13.8	1,675				80/100				30.0/30.6
50	24.0	1,670				77/110				27.0/29.5
80[2]	39.0	2,000				87/111	44	0.3	31	25.3/29.0
105	42.0	2,270				95/109				22.6/26.6
120	46.4	2,500				95/123				21.3/26.4
150[3]	55.1	3,230				108/133				19.8/25.4
180	63.0	4,000				143/164				18.0/23.6
200	67.8	4,760	2,470	6.0	219	155/182	78	0.3	18	16.4/22.3
220	72.5	5,710				180/204				15.3/21.3
240	76.8	7,680	5,490	9.0	480	232/250	118	0.3	29	14.6/20.6
255	80.0	10,000				270/306				13.8/19.3
270[3]	77.5	6,660				286/305				13.2/19.3

Table 7 (Continued)

Time mins.	Water Removed as Product % of Feed	Feed Analyses				Product Analyses				Product Flux[1] gfd
		Conductivity µmho/cm	TDS ppm	ABS ppm	COD ppm	Conductivity[1] µmho/cm	TDS ppm	ABS ppm	COD ppm	
285	78.0	7,150				293/312				13.0/17.5
300	79.2	7,400				333/357				12.5/18.0
315[3]	81.7	8,700				425/435				12.5/17.5
330	82.1	9,800	7,740	10.6	700	466/455	215	0.6	31	11.9/16.7
345	83.5	12,500				625/666				11.2/15.4

[1] The two values given for product conductivity and product flux are the separate values measured at each cell. Other analyses were carried out on a composite product from the two cells at the designated time. First cell in flow path is Cell A.

[2] Acid added to feed to adjust pH.

[3] Feed diluted with addition of filtered secondary effluent.

TABLE 8

MEMBRANE EVALUATION - 40 GFD TYPE

(Step 3, Part A of Work Statement)

Test No. 27; Pressure - 750 psig; Film No. 10-29-B7, 10-29-B8

Feed: Filtered Effluent from Azusa Water Reclamation Plant

Time mins.	Water Removed as Product % of Feed	Feed Analyses				Product Analyses				Product Flux[1] ppm
		Conductivity µmho/cm	TDS ppm	ABS ppm	COD ppm	Conductivity[1] µmho/cm	TDS ppm	ABS ppm	COD ppm	
23[2]	16.9	1,110	605	3.9	92	358/374	160	1.3	8.6	38.8/33.4
33	26.0	1,410				312/358				37.2/35.7
48[3]	22.2	1,390				351/312				32.8/32.8
60[3]	27.3	1,330				303/278				28.6/28.3
75[3]	27.2	1,280				278/270				28.1/28.9
90[2]	28.2	1,430				270/256				25.5/27.5
105	31.9	1,470				270/262				23.6/26.0
125	36.7	1,615				278/260				22.1/24.7
145	40.8	1,660				312/278				20.8/24.5
160[2]	44.3	1,790				333/286				19.1/23.5
180	48.7	1,895				358/303				19.1/23.5
200	52.6	2,080				385/324				17.2/21.5
220	56.2	2,220				417/324				16.2/19.3
240	59.6	2,440				435/324				15.5/19.7
260	63.1	2,630				455/330				14.7/19.1

Table 8 (continued)

Time mins.	Water Removed as Product % of Feed	Feed Analyses: Conductivity µmho/cm	Feed Analyses: TDS ppm	Feed Analyses: ABS ppm	Feed Analyses: COD ppm	Product Analyses: Conductivity[1] µ mho/cm	Product Analyses: TDS ppm	Product Analyses: ABS ppm	Product Analyses: COD ppm	Product Flux[1] gpd
280	66.4	2,880	1,880	5.0	187	500/358	200	0.5	9.2	13.8/18.8
300	69.6	3,030				555/385				14.0/18.2
320	72.8	3,330				588/417				13.2/17.5
340	75.7	3,700				666/475				12.9/17.1
360	78.7	4,000				720/555				12.6/16.9
380	81.6	4,550				835/589				12.1/16.2
390	83.0	4,550	3,090	5.7	N.D[4]	910/666	365	0.6	N.D.[4]	11.8/16.2

[1]The two values given for product conductivity and product flux are the separate values measured at each cell. Other analyses were carried out on a composite product from the two cells at the designated time. First cell in flow path is Cell A.

[2]Acid added to feed to adjust pH

[3]Feed diluted with addition of filtered secondary effluent.

[4]Not determined

TABLE 9

MEMBRANE EVALUATION - 50 GFD TYPE

(Step 3, Part A of Work Statement)

Test No. 25; Pressure - 750 psig; Film No. 10-23-B1, 10-23-B2

Feed - Filtered Effluent from Azusa Water Reclamation Plant

Time mins.	Water Removed as Product % of Feed	Feed Analyses				Product Analyses				Product Flux[1] gfd
		Conductivity µmho/cm	TDS ppm	ABS ppm	COD ppm	Conductivity[1] µmho/cm	TDS ppm	ABS ppm	COD ppm	
0[2]	0	780	535	2.7	44					
10	9.5	840				400/240				33.0/36.1
23	12.0	1,110				525/290				30.4/32.8
32[2]	14.4	1,250				625/370				45.8/45.0
42	21.0	1,180				590/333	284	0.5	18	45.4/48.2
52	24.9	1,290				555/323				36.8/39.8
72[2]	33.8	1,470				555/312				33.8/37.8
95	42.5	1,540				555/323				29.7/33.3
120	51.5	1,920				660/370				26.0/31.8
125	56.2	2,080				715/370	307	1.0	11	23.2/28.2
150	61.0	2,240				770/385				22.8/28.4
165	65.5	2,500				853/400				21.2/26.7
180	69.7	2,700				910/455				20.6/26.0
195	74.0	2,850				1000/525				18.3/23.7
210	78.8	3,080				1250/540				17.9/23.6
225	81.6	3,570				1430/655				17.9/23.6

Table 9 (Continued)

Time mins.	Water Removed as Product % of Feed	Feed Analyses				Product Analyses				Product Flux[1] gfd
		Conductivity µmho/cm	TDS ppm	ABS ppm	COD ppm	Conductivity[1] µmho/cm	TDS ppm	ABS ppm	COD ppm	
240	85.6	4,000				1430/770				15.9/21.3
260[3]	89.6	4,340				1930/940				21.5/29.0
280[3]	90.1	5,000				1850/1000				20.2/27.6
290[2]		3,700								
300	87.4	5,260				1790/1000				19.8/26.5
320	92.0	7,400				2080/1060				18.4/25.7
340	95.6		5,475	11.1	609	2630/1390	1062	2.0	0	17.9/24.0

[1]The two values given for product conductivity and product flux are the separate values measured at each cell. Other analyses were carried out on a composite product from the two cells at the designated time. First cell in flow path is Cell A.

[2]Acid added to feedwater to adjust pH

[3]Feed diluted with addition of filtered secondary effluent.

TABLE 10

MEMBRANE EVALUATION - 60 GFD TYPE

(Step 3, Part A of Work Statement)

Test No. 33; Pressure - 750 psig; Film No. 11-9-B9, 11-9-B10

Feed - Filtered Effluent from Azusa Water Reclamation Plant

Time mins.	Water Removed as Product % of Feed	Feed Analyses				Product Analyses				Product Flux[1] gpd
		Conductivity µ mho/cm	TDS ppm	ABS ppm	COD ppm	Conductivity[1] µ mho/cm	TDS ppm	ABS ppm	COD ppm	
0	___	715	585	6.0	115					
10	3.0	1,090				88/97				33.4/29.0
20[2]	7.4	1,120				70/82				32.6/28.3
30	10.6	1,180				72/77	27	0.4	4.0	29.8/26.1
45	15.5	1,220				65/63				29.4/25.7
60	20.5	1,250				65/61				28.4/24.5
75	24.6	1,390				65/63				26.9/23.0
90[2]	28.9	1,430				69/65				26.4/22.1
105	32.2	1,560				74/68				25.1/21.2
120	37.0	1,640				75/71				25.1/20.1
135	40.8	1,750				78/75				24.2/18.9
150	44.6	1,850				81/75				23.8/19.1
165	48.2	1,960				85/91				23.0/17.4
180	51.2	2,080	1,425	9.3	197	89/85	19	0.2	5.4	22.8/16.9
200	55.4	2,270				96/91				23.9/15.2
220	60.3	2,500				104/100				23.4/15.1

Table 10 (Continued)

Time mins.	Water Removed as Product % of Feed	Feed Analyses				Product Analyses				Product Flux[1] gfd
		Conductivity µmho/cm	TDS ppm	ABS ppm	COD ppm	Conductivity[1] µmho/cm	TDS ppm	ABS ppm	COD ppm	
240	64.9	2,860				116/83				22.1/15.5
260	69.0	3,220				135/132				20.9/14.5
280	73.0	3,840	2,380	14.2	335	162/156	51	0.3	10.0	20.5/14.2
300	78.0	4,550				200/195				19.5/13.1
320	80.6	5,700	3,930		520	260/240	68		10.2	18.4/12.5
340	84.0	8,000	5,210	24.0	685	350/395	174	0.4	19.0	17.6/11.6

[1] The two values given for product conductivity and product flux are the separate values measured at each cell. Other analyses were carried out on a composite product from the two cells at the designated time. First cell in flow path is Cell B

[2] Acid added to feedwater to adjust pH

TABLE 11

MEMBRANE EVALUATION - 60 GFD TYPE

(Step 3, Part A of Work Statement)

Test No. 36; Pressure - 750 psig; Film No. 12-2-B2, 12-2-B3

Feed - Filtered Effluent from Azusa Water Reclamation Plant

Time mins.	Water Removed as Product % of Feed	Feed Analyses				Product Analyses				Product Flux[1] gfd
		Conductivity µmho/cm	TDS ppm	ABS ppm	COD ppm	Conductivity[1] µmho/cm	TDS ppm	ABS ppm	COD ppm	
0		805	535	5.5	90					
7							145	---[3]	6.3	
26		1,030								
40[2]	10.4									16.3/19.4
60	16.3	1,540				140/140	120	0.1	10	20.6/23.6
80	22.1	1,690				132/116				20.4/21.0
100	28.0	1,850				139/120				20.6/23.0
120	34.0	2,080	1,350	7.3	150	147/122	60	0.2	8.0	20.6/22.8
140	40.0	2,320				172/139				20.6/22.8
160	45.6	2,650				193/150				20.6/22.0
180[2]	51.5	3,300	1,890	10.0	225	230/185	90	0.3	13.5	20.9/21.6
200	57.0	2,560				200/156				20.5/20.9
220	62.5	3,030				212/166				19.7/19.7
240	68.0	3,570				240/195				20.4/19.7
260	73.0	4,350				300/240				20.4/18.7

Table 11 (Continued)

Time mins.	Water Removed as Product % of Feed	Feed Analyses				Product Analyses				Product Flux[1] gfd
		Conductivity µmho/cm	TDS ppm	ABS ppm	COD ppm	Conductivity[1] µmho/cm	TDS ppm	ABS ppm	COD ppm	
270		5,000	3,000	14.0	310	345/280	155	0.3	15.0	20.2/18.0
280	78.6	5,400				390/310				22.8/18.8
300	83.2	7,400				500/400				18.6/16.5
320	87.8	12,500	8,230	28.2	735		320	0.6	19.5	17.6/14.5

[1] The two values given for product conductivity and product flux are the separate values measured at each cell. Other analyses were carried out on a composite product from the two cells at the designated time. First cell in flow path is Cell B.

[2] Acid added to feedwater to adjust pH.

[3] Sample destroyed during ABS analysis.

TABLE 12

MEMBRANE EVALUATION - 10 GFD TYPE

(Step 4, Part A of Work Statement)

Test No. 31; Pressure - 1500 psig; Film No. 11-15-B5 on A, 11-15-B2 on B

Feed - Filtered Effluent from Azusa Water Reclamation Plant

Time mins.	Water Removed as Product % of Feed	Feed Analyses				Product Analyses				Product Flux[1] gfd
		Conductivity µmho/cm	TDS ppm	ABS ppm	COD ppm	Conductivity[1] µmho/cm	TDS ppm	ABS ppm	COD ppm	
Start-up[2]	5.9	910	620	5.5	86		63	0.4	7.2	
10[3]	8.0					63/39				25.7/22.0
20						44/35				24.2/21.3
30	14.1	1,280				67/33				23.9/20.2
45	15.4	1,300								23.5/19.8
60[2]	18.9	1,360				42/32				22.2/19.8
75[2]		1,490				45/33				22.2/19.6
90	26.0	1,610				46/33				21.6/19.1
110		1,780				46/33				21.3/18.7
130		1,930				48/33				21.2/18.7
150	39.4	2,130	1,226	7.3	130	47/33	52	0.2	8.4	20.4/17.2
170		2,270				48/33				19.5/17.5
180	45.6	2,320				47/35				19.5/16.9

Table 12 (Continued)

Time mins.	Water Removed as Product % of Feed	Feed Analyses				Product Analyses				Product Flux[1] gfd
		Conductivity μ mho/cm	TDS ppm	ABS ppm	COD ppm	Conductivity[1] μ mho/cm	TDS ppm	ABS ppm	COD ppm	
200	49.6	2,560				48/34				18.7/16.5
220		2,780				51/76				17.8/16.0
240	57.0	3,130				52/39				17.5/15.4
260		3,450				57/43				17.3/15.3
280	64.0	3,850	2,164	11.6	205	67/47	33	0.3	12.9	16.7/14.7
300	68.0	4,350				71/54				16.0/14.2
320		4,750				82/63				15.6/13.7
330	73.0	5,400								
330[4]	6.1	1,960	1,418	8.5	153	68/53	43	0.3	6.0	18.0/17.0
370	12.3	2,220				53/128				18.0/17.1
390	18.4	2,380				69/167				17.9/17.5
410[2]	24.6	2,630				65/213				17.6/17.6
430	30.5	2,820				67/322				17.3/17.3
450	36.8	3,100				83/322	110	0.6	14.0	17.6/17.3
470	39.8	3,200				78				17.0
490	42.8	3,300				78				17.0
510	47.8	3,570				74				16.9
530	50.7	3,850				80				18.4

Table 12 (Continued)

Time mins.	Water Removed as Product % of Feed	Feed Analyses				Product Analyses				Product Flux[1] gfd
		Conductivity µmho/cm	TDS ppm	ABS ppm	COD ppm	Conductivity[1] µmho/cm	TDS ppm	ABS ppm	COD ppm	
550[2]	53.6	4,250	2,342	12.0	216	83	31	0.2	11.0	18.4
570	56.4	4,650				88				15.6
590	59.0	5,120				98				15.4
610	61.6	5,720				104				14.9
630	64.5	6,450	4,146	17.0	325	116	39	0.2	15.0	14.7

[1] The two values given for product conductivity and product flux are the separate values measured at each cell in order of flow sequence. Other analyses were carried out on composite product from the two cells at the designated time. The first cell in the flow path is Cell B.

[2] Acid added to feed water to adjust pH.

[3] Feed water diluted with addition of filtered secondary effluent.

[4] Second portion of film test continued following overnight shutdown and addition of filtered secondary effluent to feed.

TABLE 13

MEMBRANE EVALUATION - 20 GFD TYPE

(Step 4, Part A of Work Statement)

Test No. 30; Pressure - 1500 psig; Film No. 11-12-B2, 11-12-B4

Feed - Filtered Effluent from Azusa Water Reclamation Plant

Time mins.	Water Removed as Product % of Feed	Feed Analyses				Product Analyses				Product Flux[1] gfd
		Conductivity μmho/cm	TDS ppm	ABS ppm	COD ppm	Conductivity[1] μmho/cm	TDS ppm	ABS ppm	COD ppm	
0[2]		920								
14		1,160	542	4.1	103	82				32.8
25	5.8	1,220				72				32.0
38[2]	8.4	1,280				50				31.6
50	10.9	1,390				56				31.2
70	14.8	1,430				53				
90	17.4	1,590				50	21	0.2	8.5	
105	20.0	1,660				50				25.0
120[2]	22.5	1,760				57				24.2
135	24.8	1,850				53				23.7
150	27.1	1,920				69				22.5
165	28.3	2,000				60				21.3
180	31.6	2,080				60				22.5
200	34.2	2,170				55				19.7

Table 13 (continued)

Time mins.	Water Removed as Product % of Feed	Feed Analyses				Product Analyses				Product Flux[1] gfd
		Conductivity μ mho/cm	TDS ppm	ABS ppm	COD ppm	Conductivity[1] μ mho/cm	TDS ppm	ABS ppm	COD ppm	
220	36.7	2,270				45				19.7
240	39.2	2,380				45				18.0
260	41.6	2,500	1,350	6.5	153	50	37	0.1	11.0	18.0
260[3]		1,600	986	6.2	120					
275[2]		1,750				73/69				18.7/27.2
290	11.4	2,000				97/110	63	0.2	11.0	24.7/18.4
305	16.7	2,220				91/122				23.8/17.9
320	21.8	2,320				89/128				22.6/17.7
340	28.3	2,700				88/132				21.3/16.9
360	34.7	2,940				89/62				22.6/17.7
380	40.6	3,220				91/64				19.7/15.3
400	46.4	3,570				90/69				18.9/14.9
420	52.0	4,000	2,030	8.4	213	106/77	16	0.1	14.0	18.0/13.5
440	57.2	4,350				113/82				19.1/14.5
460	63.0	5,000				132/95				16.9/16.0
480	67.7	6,050	3,164			147/111	38			13.2/15.2
500	72.4	7,150				182/132				14.6/12.5

Table 13 (continued)

Time mins.	Water Removed as Product % of Feed	Feed Analyses				Product Analyses				Product Flux[1] gfd
		Conductivity µmho/cm	TDS ppm	ABS ppm	COD ppm	Conductivity[1] µmho/cm	TDS ppm	ABS ppm	COD ppm	
520	76.6	8,320				200/154				13.6/12.0
540	80.8	11,100	6,684	16.0	547	256/196	95	0.2	28.3	13.1/11.6

[1]One film was tested during the first 260 minutes on Cell B. Following overnight shutdown and addition of filtered secondary effluent to feed the test was resumed with the same film on Cell B and a new film was mounted on Cell A. The first cell on the flow line was Cell B, and the values appear in order of flow sequence.

[2]Acid added to feed water to adjust pH

[3]Feed diluted with addition of filtered secondary effluent.

TABLE 14

MEMBRANE EVALUATION - 40 GFD TYPE

(Step 4, Part A of Work Statement)

Test No. 29; Pressure - 1500 psig; Film No. 10-28-B6, 10-28-B7

Feed - Filtered Effluent from Azusa Water Reclamation Plant

Time mins.	Water Removed as Product % of Feed	Feed Analyses				Product Analyses				Product Flux[1] gfd
		Conductivity μmho/cm	TDS ppm	ABS ppm	COD ppm	Conductivity[1] μmho/cm	TDS ppm	ABS ppm	COD ppm	
0[2]		1,090	527	5.0	88					
10[2]	8.6	1,180								37.0/41.0
22	14.0	1,280								40.0/43.3
32	19.0	1,390								38.9/38.9
42	23.2	1,560	965	5.5	120		27	0.2	11.0	31.9/33.4
55[2]	20.8	1,670								31.2/33.9
60[3]	20.2	1,540				65/56				30.1/32.3
75	23.9	1,470				64/54				27.4/30.5
90	27.5	1,515				52/55				26.4/29.4
106	31.2	1,560				55/66				25.4/28.2
120	34.0	1,670				73/64				23.2/25.7
135[3]	33.0	1,790				94/59				23.5/25.8
150	35.5	1,750				94/61				21.5/23.5
165	38.2	1,850				88/64				22.0/24.2

Table 14 (Continued)

Time mins.	Water Removed as Product % of Feed	Conductivity µmho/cm	TDS ppm	ABS ppm	COD ppm	Conductivity[1] µmho/cm	TDS ppm	ABS ppm	COD ppm	Product Flux[1] gfd
180	40.4	1,920				88/72				21.0/22.0
200	43.5	2,080	1,230	6.2	115	91/87	31	0.2	10.0	20.6/21.3
220	46.5	2,170				93/100				18.6/20.1
240	49.2	2,270				128/107				18.2/19.7
260	52.2	2,380				179/125				18.2/19.7
280[4]	55.0	2,500				237/357				17.6/20.6
300	58.3	2,560				222/590				18.7/23.9
315	60.6	2,780				244/715				18.4/25.7
335	64.0	3,030	1,765	9.4	175	179/715	255	1.3	32.0	16.6/23.2
350[5]	66.4	2,960	1,650	25	175	370/666				13.5/29.5
365[2]	68.5	3,130				475/685				13.7/28.2
						A 486	302	1.0	28.0	
						B 625	425	2.0	45.0	
380	71.0	3,700				345/535				16.3/26.5
395	73.5	4,170	2,371	11.0	228	645/940				16.9/26.2

Table 14 (Continued)

Time mins.	Water Removed as Product % of Feed	Feed Analyses				Product Analyses				Product Flux[1] gfd
		Conductivity µmho/cm	TDS ppm	ABS ppm	COD ppm	Conductivity[1] µmho/cm	TDS ppm	ABS ppm	COD ppm	
415	75.4	4,760				645/960				15.3/23.8
435	79.1	5,260				500/1020				13.4/22.4
455	82.0	6,060				715/1260				13.7/21.3
475	83.5	7,140								12.8/21.3
485	85.7	8,340	4,650	16.0	417		685	2.3	58.0	

[1] The two values given for product conductivity and product flux are the separate values measured at each cell. Other analyses were carried out on a composite product from the two cells at the designated time. The first cell in the flow path is Cell A.

[2] Acid added to feed water to adjust pH.

[3] Feed water diluted with addition of filtered secondary effluent.

[4] Building evacuated and test interrupted for 20 minutes.

[5] Second portion of test following overnight shutdown continued with same films and same feed water.

TABLE 15

MEMBRANE EVALUATION - 50 GFD TYPE

Test No. 37; Pressure - 1500 psig; Film No. 12-3 B5 and B11

Feed - Filtered Effluent from the Azusa Water Reclamation Plant

Time mins.	Water Removed as Product % of Feed	Feed Analyses				Product Analyses				Product Flux[1] gfd
		Conductivity μmho/cm	TDS ppm	ABS ppm	COD ppm	Conductivity[1] μmho/cm	TDS ppm	ABS ppm	COD ppm	
0[2]		900	595	5.6	100		35	0.2	7.2	
9	3.24	1,100				91				35.3
20		1,390				82				36.0
30	10.0	1,390				72				36.0
40	13.0	1,470				80				36.0
50[3]	17.2	1,560				86				32.0
70[2]	24.5	1,850				83				31.6/48.0
80	30.6	2,040				80/81				30.9/41.8
90	36.2	2,170	1,265	7.2	145	85/82	36	0.2	10.0	28.0/37.4
100[4]	41.5	2,440				86/83				26.4/36.0
110	30.9	1,830				86/83				24.6/32.4
120	34.0	2,000				80/80				23.9/31.0
135	38.5	2,180				87/83				23.3/29.7
150	42.7	2,220				92/88				22.2/23.9
165	47.0	2,500				100/91				21.5/25.9
180	50.8	2,780				109/100				21.0/24.5

Table 15 (Continued)

Time mins.	Water Removed as Product % of Feed	Feed Analyses				Product Analyses				Product Flux[1] gfd
		Conductivity µmho/cm	TDS ppm	ABS ppm	COD ppm	Conductivity[1] µmho/cm	TDS ppm	ABS ppm	COD ppm	
195	54.5	2,860				119/116				20.0/23.2
210	58.0	3,330	2,025	10.2	205	128/116	44	0.2	8.5	19.3/21.3
230	62.3	3,840				147/128				18.1/20.2
250	66.5	4,550				169/153				17.8/19.0
270	70.6	5,260				204/185				17.3/18.0
290	74.2	6,550	3,645	13.4	335	227/250	67	0.3	13.0	16.2/16.4
310	77.6	8,000				322/286				15.0/15.4
330	81.0	11,800	7,185	22.0	575	435/385	135	0.3	15.5	14.3/14.6
0[5]			565	5.0	85					
10	4.5	1,140				77/67	46	0.2	3.5	27.2/25.0
21	8.8	1,250				64/62				24.0/23.0
40	16.4	1,390				74/66				24.0/23.0
60	24.1	1,670				71/66	39	0.2	6.0	24.0/21.3
82.5	32.5	1,920				83/77				22.2/21.2
100	38.9	1,920				89				22.0/21.0
120	45.3	2,270				83/91				19.7/18.0
130[6]	46.8		1,354	7.0	157		41	0.2	4.6	

Table 15 (Continued)

Time mins.	Water Removed as Product % of Feed	Feed Analyses				Product Analyses				Product Flux[1] gfd
		Conductivity µmho/cm	TDS ppm	ABS ppm	COD ppm	Conductivity[1] µmho/cm	TDS ppm	ABS ppm	COD ppm	
140	50.0	2,700				109				19.0
160	53.2	2,940				110				18.4
180	56.2	3,570				117				17.6
200	59.2	3,280				130				17.3
220	61.9	3,580	1,879	9.0	212	143	50	0.3	8.0	16.3
240	64.7	3,920				154				16.0
260	67.2	4,250				172				15.4
280	69.8	4,760				196				14.9
300	72.3	5,400				217				14.5
320	74.5	6,050				250				13.2
340	76.6	6,666	3,836	13.3	343	294	106	0.3	10.7	13.0

[1] The two values given for product conductivity and product flux are the separate values measured at each cell in order of flow sequence. Other analyses were carried out on composite samples from the two cells at designated times. The first cell in the flow path is Cell B.

[2] Add acid to adjust feed water pH.

[3] Start test of second film.

[4] Added filtered secondary effluent to feed water.

[5] Second part of test (37B) following overnight shutdown utilizing same films and new supply of filtered secondary effluent.

[6] Cell A leaked at "O-ring" seal and test discontinued.

TABLE 16

PRODUCT WATER QUALITY

Test No.	Film Flux Type (gfd)	Product Composition (calculated composite) TDS ppm	ABS ppm	COD ppm	Feed Composition TDS(ppm) initial/final	ABS(ppm) initial/final	COD(ppm) initial/final	% Feed Collected as Product[1]
21	10	53	0.1	9	825/7515	2.9/5.4	130/670	85.0
23	20	23	0.1	10	930/5315	4.3/6.8	112/451	82.7
24	30	72	0.3	27	560/7740	3.0/10.6	88/700	83.5
27	40	190	0.9	—[2]	605/3090	3.9/5.7	92/ —[2]	83.0
25	50	375	0.9	12	535/5475	2.7/11.1	44/609	95.6
33	60	34	0.3	6	585/5208	6.0/24.0	115/685	84.0
36	60	127	0.3	12	535/8230	5.5/28.2	90/735	87.8
31	10	60	0.3	10	620/4145	5.5/17.0	86/325	68.5
30	20	42	0.2	14	542/6684	4.1/16.0	103/547	78.5
28	30	53	0.1	10	595/6290	5.0/17.6	110/500	83.0
29[3]	40	30	0.2	10	527/1230	5.0/6.2	88/115	49.2
37(A)	50	47	0.2	9	595/7185	5.6/22.0	100/575	81.0
37(B)	50	48	0.2	6	565/3836	5.0/13.3	85/343	76.6

[1] Excluding samples

[2] Insufficient data

[3] First four hours of test, whereupon one film deteriorated and caused abnormally high values.

TABLE 17

(Supplementary Test)

Test No. 35; Pressure - 750 psig; Film No. 11-22-B7, 11-21-B18

Water: Sodium chloride brine approximately 1500 ppm

Time min.	Water Removed as Product % of Feed	Feed Analysis Conductivity µmho/cm	Product Analysis Conductivity[1] µmho/cm	Product Flux[1] gfd
0		2,250		
20		2,500	128/131	16.2/18.0
40	5.0	2,700	135/137	18.1/20.0
60	10.5	2,940	149/154	18.7/20.6
80	16.2	3,220	169/164	20.6/22.5
100	22.4	3,700	178/185	20.3/22.1
120	28.6	3,840	196/204	20.3/22.8
140	35.0	4,160	217/230	22.1/23.9
160	41.5	4,550	244/256	22.5/23.2
180	48.7	5,260	270/276	20.2/21.8
200	54.2	5,880	303/312	21.2/23.0
220	60.5	6,660	345/357	20.6/22.3
240	66.5	8,000	400/430	20.6/22.3
260	72.8	10,000	500/526	20.4/21.9
280	78.8	12,500	625/645	20.1/21.1
290	85.5	14,300	780	18.3
300[2]	85.5	14,300	780	18.3
305	85.5	14,300	780	18.3
310	85.5	14,300	780	18.3
315	85.5	14,300	780	18.3
320	85.5	14,300	780	18.3
325	85.5	14,300	780	18.3
330	85.5	14,300	780	18.3

Table 17 (Continued)

Time mins.	Water Removed as Product % of Feed	Feed Analysis Conductivity µmho/cm	Product Analysis Conductivity[1] µmho/cm	Product Flux[1] gfd
340	85.5	14,300	780	18.3
355	85.5	14,300	780	18.0
370	85.5	14,300	780	18.0
385	85.5	14,300	780	18.0

[1]The two values given for product conductivity and product flux are the separate values measured at each cell in order of flow sequence. Other analyses were carried out on composite samples from the two cells at designated times. The first cell in the flow path is Cell B.

[2]Product returned to feed tank and constant feed concentration maintained. Flux and product conductivity values are average value for both cells.

TABLE 18

THREE DAY TEST

Test No. 40; Pressure - 1500 psig; Film No. 12-3-B7

Feed - Filtered Effluent of Azusa Water Reclamation Plant

Charcoal treated and filtered through Whatman No. 5 Filter Paper until clear; pH adjusted to 4.8

Time (hours)	Feed Conductivity µmho/cm	Product Conductivity µmho/cm	Flux (gfd)
0	1,250	70	40
2	1,250		40
4	1,500	66	38.5
5	1,600		37.5
22			24.5
23			23.5
24[1]	1,300	75	23.5
25.5			22.5
28.5			22.0
44.5			19.5
48	1,270	85	18.5
51[1]			16.5
53			17.5
69	1,200	85	15
72	1,200	85	14

[1] Feed exchanged for freshly obtained waste water after charcoal treatment.

TABLE 19

MEMBRANE TEST WITH DEIONIZED WATER FEED AT 750 PSI

Date	Pressure (psi)	CELL A Total Operating Time Days	CELL A Total Operating Time Hours	CELL A Flux (gfd)	CELL B Total Operating Time Days	CELL B Total Operating Time Hours	CELL B Flux (gfd)
9/17/64	750			leaks	0		33.2
9/18/64	760			-		16	31.7
			0	38.9	1	0	30.5
9/21/64	700	2	16	30.9	3	16	25.9
	720	3	0	32.4	4	0	26.7
9/22/64	750	3	16	35.1	4	16	29.0
	750	4	0	32.8	5	0	27.5
9/23/64	750	4	16	32.8	5	16	27.1
	750	5	0	32.8	6	0	27.1
9/24/64	750	5	16	32.8	6	16	27.5
	745	6	0	32.8	7	0	27.5
9/25/64	735	6	16	32.0	7	16	26.3
	735	7	0	32.8	8	0	27.0*
9/28/64	730	9	16	29.8	10	16	24.8*
	750	10	0	33.6	11	0	27.5*
9/29/64	735	10	16	31.7	11	16	26.7*
	760	11	0	33.2	12	0	27.8
9/30/64	750	11	16	32.1	12	16	26.7
	750	12	0	31.7	13	0	26.7
10/1/64	750	12	17	31.6	13	17	25.9

* System depressurized to change gages.

Reading taken on deionized water feed and feed substituted with 750 ppm NaCl solution. See Table 20 for continuation of test.

TABLE 20

MEMBRANE TEST WITH 750 PPM NaCl SOLUTION AT 750 PSI

(Following Film Conditioning with Deionized Water Feed at 750 psi)

		CELL A					CELL B				
		Total Operating Time					Total Operating Time				
Date	Pressure	Days	Hrs.	Conductivity $\mu mho/cm^2$	Flux (gfd)	Salt Content ppm NaCl	Days	Hrs.	Conductivity $\mu mho/cm^2$	Flux (gfd)	Salt Content ppm NaCl
10/1/64	755	12	19	100	32.0	46	13	19	60	26.7	27
	755	12	22	100	32.0	46	14	0	60	26.7	27
10/2/64	755	13	16	90	32.0	43	14	16	60	27.1	27
	755	14	0	100	30.5	46	15	0	60	25.2	27
10/5/64	755	16	16	100	29.0	46	17	16	60	24.4	27
	745	17	0	100	30.1	46	18	0	60	25.2	27
10/6/64	755	17	16	100	29.8	46	18	16	60	24.8	27
	750	18	0	100	30.1	46	19	0	60	25.2	27
10/7/64	755	18	17	120	29.0	58	19	17	60	24.8	27
	750	19	0	130	29.4	66	20	0	70	25.2	33
10/8/64	750	19	16	120	29.0	58	20	16	65	24.4	30
	750	20	0	120	29.7	58	21	0	65	25.2	30
10/9/64	760	20	16	110	28.6	54	21	16	60	24.4	27
		21	0	100	28.2	46	22	0	60	24.0	27
10/12/64	750	23	16	100	27.4	46	24	16	60	23.6	27
	750	24	0	110	27.4	54	25	0	60	24.0	27
10/13/64	760	24	16	110	27.8	54	25	16	60	24.4	27
	760	25	0	110	27.5	54	26	0	60	24.0	27

TABLE 21

MEMBRANE TEST WITH 750 PPM NaCl SOLUTION, FOLLOWED BY EFFLUENT OF AZUSA WATER RECLAMATION PLANT AT 750 PSI

		Feed Water Analyses					Product Water Analyses			
Date	Pressure psi	Temp °C	Conductivity[1] µmho/cm	pH	Total Operating Time Days	Hours	Conductivity[1, 2] µmho/cm	Product Flux[2] (gfd)	pH[2]	Remarks
10/27/64	750	23		-	0	1	160/220	34.9/32.0	-	Feed water: deionized water with 750 ppm NaCl.
	749	23	1550	-		2	90/100	34.8/32.0	-	
	748	23	1550	-		3	80/90	34.8/32.0	-	
	748	21	1550	-		7	85/105	31.6/29.8	-	
10/28/64	743	23	1525	-		20	70/80	31.6/30.1	-	
	744	23	-	-		23	70/75	30.5/29.0	-	
	749	21	1500	-	1	4	70/80	31.3/29.8	-	
	750	21	1550	-	1	11	85/90	31.7/29.8	-	
10/29/64	748	21	1500	-	1	20	65/75	32.4/30.0	-	
	745	21	-	-	2	0	70/80	30.9/28.6	-	
	750	21	1500	-	2	3	75/80	29.4/28.6	-	
10/30/64	748	21	1600	-	2	20	70/80	29.0/27.8	-	
	750	21	1525	-	3	3	70/80	29.4/28.2	-	
	750	20	1450	-	3	10	75/95	29.4/28.2	-	
11/2/64	740	20	-	-	5	20	70/80	29.0/27.8	-	
	747	20	1550	-	6	0	70/80	27.5/26.4	-	
	750	20	1550	-	6	11	65/80	26.7/25.9	-	
11/3/64	748	20	1550	-	6	20	65/75	27.5/25.9	-	
	749	21	1550	-	7	0	65/75	27.5/25.9	-	
	751	20	1550	-	7	11	70/85	27.5/25.9	-	

Table 21 (continued)

Date	Pressure psi	Feed Water Analyses: Temp °C	Conductivity[1] µmho/cm	pH	Total Operating Time: Days	Hours	Product Water Analyses: Conductivity[1,2] µmho/cm	Product Flux[2] (gfd)	pH[2]	Remarks
11/4/64	750	20	1550	-	7	20	65/80	28.2/26.7	-	
	750	20	1500	-	8	0	60/70	27.1/25.9	-	
	754	20	1550	-	8	10	65/70	27.8/26.7	-	
11/5	754	20	1600	-	8	20	65/70	28.2/27.1	-	
	750	-	1550	6.9	9	2	60/70	29.8/31.6	-	Add acidified waste water
	756	19	1200	4.3	9	5	40/45	23.6/22.5	5.1/5.2	Organic carbon analysis (mg/l) Feed 20; Product 1.0; Recycle 21.5
	756	19	1200	4.5	9	11	<40/<40	19.1/21.0	-	
11/6	756	22.8	-	5.1	9	20	19.5/22	19.8/16.8	-	
	756	23.5	-	-	10	0	19.5/21	21.4/17.9	-	Feed changed. Organic carbon analysis (mg/l)- Product 1.0
	750	21.4	920	4.8	10	3	30	19.1/15.6	5.0	
	750	21.5	920	5.4	10	10	20/22	17.5/14.5	5.1/5.4	
11/7	753	21.6	920	5.9	11	0	15/20	16.0/13.7	6.0/6.3	
11/8	750	21.8	920	6.0	12	0	15/24	15.9/12.0	6.0/6.0	
11/9	755	20.6	950	6.6	12	20	28.5	15.1/11.5	4.5	
	752	22.7	1000	5.9	13	0	20.5	16.4/12.6	5.9	Feed water changed.
	750	19.0	1140	4.9	13	2	33.0	14.5/11.5	5.3	Organic carbon analysis(mg/l)-Feed 18.5; Product 2.5; Reject 15.5

Table 21 (continued)

Date	Pressure psi	Feed Water Analyses: Temp °C	Conductivity[1] µmho/cm	pH	Total Operating Time: Days	Hours	Product Water Analyses: Conductivity[1,2] µmho/cm	Product Flux[2] (gf'd)	pH[2]	Remarks
11/10/64	748	19.0	1140	5.8	13	20	18.0	13.6/10.7	5.3	
	753	21.7	1140	6.0	14	0	18.0	15.3/11.5	5.9	Feed water changed
	755	20.2	920	3.8	14	3	28.0	13.7/10.7	5.2	Organic carbon analysis(mg/l) - Product 1.0
	756	21.0	920	4.2	14	10	25.0	13.1/10.1	5.6	
	755	19.6	920	4.4	14	20	21.0	12.2/9.9	5.7	
	755	23.6	920	5.4	15	1	20.0	14.3/10.9	5.9	Organic carbon analysis (mg/l)- Feed 17.5 Product 3.5; Reject 16.0
	755	18.9	900	-	15	3	-	12.2/9.5	-	Changed feed. Organic carbon analysis (mg/l)-Product <1.0
		20.7	900	5.2	15	11	24.0	12.2/9.5	5.7	
11/12/64	755	19.5	890	5.7	15	20	16.0/19.0	12.2/9.3	5.9/6.1	

[1] Corrected to 25°C.

[2] The two numbers given are the separate values as measured at each cell in order of flow sequence (Cell B then Cell A).

TABLE 22

MEMBRANE TEST WITH 750 PPM NaCl SOLUTION FOLLOWED BY TREATED EFFLUENT

		Feed Water Analyses			Total Operating Time		Product Water Analyses				Organic Carbon Analysis			
Date	Pressure psi	Temp °C	Conductivity[1] µmho/cm	pH	Days	Hours	Conductivity[1,2] µmho/cm	Product Flux[2] (gfd)	pH	Remarks	Untreated Effluent	Treated Effluent	Product	Reject
12/4/64	750	23.7	1475	7.10	0	1	135/135	36.8/34.7	6.4/6.0					
	751	24.0	1450	7.00	0	2	140/120	36.2/34.2	6.4/6.1					
	753	24.7	1475	7.00	0	11	130/110	35.8/33.8	6.0/6.3					
12/7/64	757	22.3	1600	6.60	2	16	130/127	32.8/31.6	6.5/6.2					
	755	21.2	1600	6.70	2	22	127/127	29.7/28.6	6.1/6.1	Pressure cycling started				
	760	20.8	1600	6.80	3	0	78/92	30.9/29.4	6.1/6.2					
12/8/64	754	20.4	1550	7.10	3	11	88/94	30.5/29.0	6.1/6.4					
	758	20.0	1600	7.05	3	16	90/100	30.1/28.6	5.9/6.1					
	756	20.0	1575	7.00	4	3	84/90	29.4/27.8	6.0/6.0					
	754	19.3	1575	7.00	4	11	78/99	29.0/27.4	6.0/6.0					
12/9/64	755	19.0	1625	6.85	4	16	86/92	29.0/27.4	6.1/6.4		25.5	-	-	-
	750	19.4	1600	7.00	5	3	81/88	28.6/27.1	6.1/6.1					
	752	19.8	1575	6.90	5	7	79/92	29.0/27.4	6.0/6.1					
12/10/64	751	18.8	1650	6.90	5	20	80/99	28.6/27.1	6.1/6.2		18.5	3.0	2.0	-
	757	19.5	1800	2.80	6	2	93/97	27.4/26.9	3.8/3.8	Treated effluent Batch 1				
	759	19.5	1750	2.80	6	4	96/97	27.1/25.0	3.7/3.7					
12/11/64	759	21.7	1850	2.80	6	18	97/88	25.9/24.1	3.9/3.9		20.0	-	-	-
	760	20.4	1850	2.85	6	22	97/90	26.3/25.2	3.9/3.9					
	870	20.8	1120	3.65	7	3	31/36	25.7/24.8	5.5/5.4	Feed Batch 2				

TABLE 22 (Continued)

Date	Pressure psi	Feed Water Analyses: Temp °C	Conductivity[1] µmho/cm	pH	Total Operating Time: Days	Hours	Product Water Analyses: Conductivity[1,2] µmho/cm	Product Flux 2 (gfd)	pH	Remarks	Organic Carbon Analysis: Untreated Effluent	Treated Effluent	Product	Reject
12/14/64	756	20.7	1150	3.70	9	18	35/38	25.2/24.4	5.8/5.7		24.0	2.0	1.0	-
	757	19.4	1225	3.75	9	22	32/38	25.2/24.4	5.8/5.9					
	757	21.3	1120	3.85	10	3	32/39	25.0/24.1	5.7/5.8	Feed Batch 3				
	757	19.7	1120	3.75	10	5	35/39	25.7/25.0	5.7/5.6					
12/15/64	756	19.8	1150	-	10	18	32/40	25.0/24.4	5.9/5.8		-	4.0	1.5	-
	752	21.4	1120	3.90	10	22	34/41	25.0/24.1	5.9/5.8					
	755	20.5	1050	3.88	11	3	37/42	25.4/24.4	5.5/5.5	Feed Batch 4				
	756	19.0	1130	3.80	11	5	37/41	25.0/24.0	5.5/5.4		-	11.5	9.0	14.0
12/16/64	754	19.6	1050	3.90	12	3	37/42	25.2/24.4	5.7/5.4	Feed Batch 5				
	752	19.6	1030	4.0	12	5	34/41	25.4/24.1	5.6/5.5					
12/17/64	752	20.7	950	4.0	12	18	36/42	27.5/24.6	—		23.0	9.0	7.0	-
	755	20.3	1020	3.8	13	3	44/41	26.8/25.5	5.5/5.6					
	758	20.0	1040	3.9	13	5	34/45	26.6/25.8	5.4/5.5					
12/18/64	749	19.3	1120	3.9	13	18	34/41	26.1/24.8	5.6/5.6		20.5	2.0	1.0	2.5
	753	20.0	1040	3.9	14	3	115/43	26.2/26.2	5.7/5.4	Feed Batch 6				
	748	19.5	1040	3.9	14	5	110/38	26.2/26.7	5.2/4.9					
12/21/64	757	19.3	1080	4.5	16	18	71/17	29.0/25.5	6.4/5.4		23.0	2.5	<1.0	2.5
	752	21.2	1060	4.0	17	0	66/72	27.1/26.6	5.4/5.5	Feed Batch 7				
12/22/64	760	20.5	1040	4.5	17	18	310/100	34.2/26.0	5.2/5.7			<1.0	<1.0	
	760	20.5	1040	4.5	17	20	150/86	29.0/25.4	5.5/5.6	Feed Batch 8				
12/23/64	750	21.0	1020	4.0	18	18	320/158	31.8/23.2	-	Not carbon treated		8.0	<1.0	7.5
	750	20.0	815	4.1	19	0	135/51	29.4/22.1	-					
	745	20.1	990	5.1	23	18	370/124	30.1/19.7	5.5/5.3					

[1] Corrected to 25°C.

[2] The two numbers given represent the separate values as measured at each cell in order of flow sequence (Cell B, then Cell A).

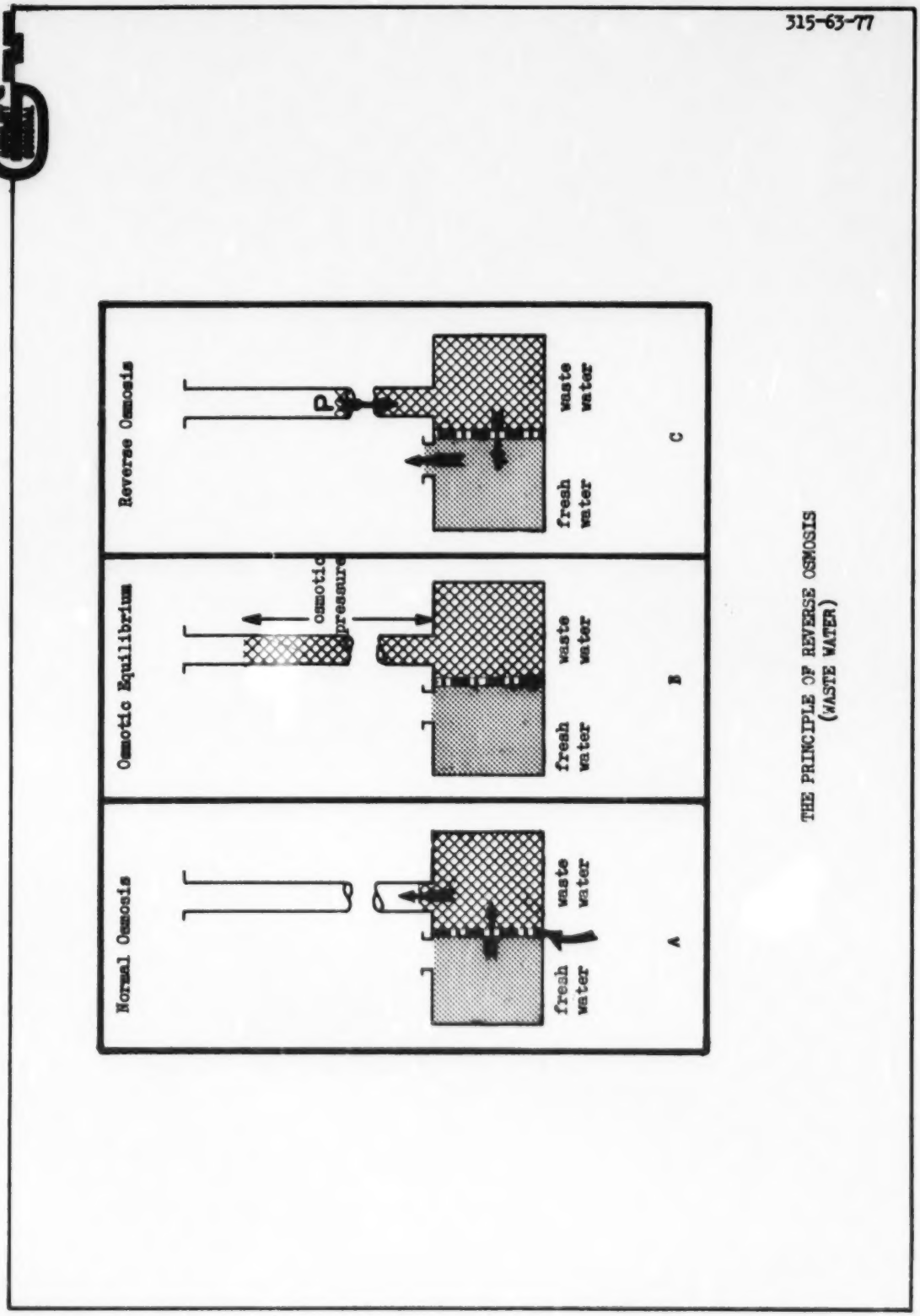
TABLE 23

FILM IMMERSION TEST RESULTS[1]

Date	Immersion Time (Days)	Test Results[2] (Avg.) No. Circles Tested	Flux (gfd)	Salt (ppm NaCl)	Three-Test Average Flux (gfd)	Three-Test Average Salt (ppm NaCl)
10/27	0	4	18.5	975		
11/5	9	6	18.5	925		
11/11	15	5	19.6	900	18.9	935
11/18	22	6	19.3	1015	19.1	945
11/23	27	5	19.7	1340	19.5	1085
11/30	34	6	18.7	1100	19.2	1150
12/7	41	6	20.7	1075	19.7	1170
12/15	49	6	23.2	1180	20.9	1120
12/22	56	6	21.2	1090	21.7	1115
12/29	63	6	21.2	1220	21.9	1165

[1] Cellulose acetate films stored in a container in the reject stream flow path.

[2] Tested with 3.5% NaCl solution at 1500 psig with standard test procedures.



THE PRINCIPLE OF REVERSE OSMOSIS
(WASTE WATER)

Figure 1

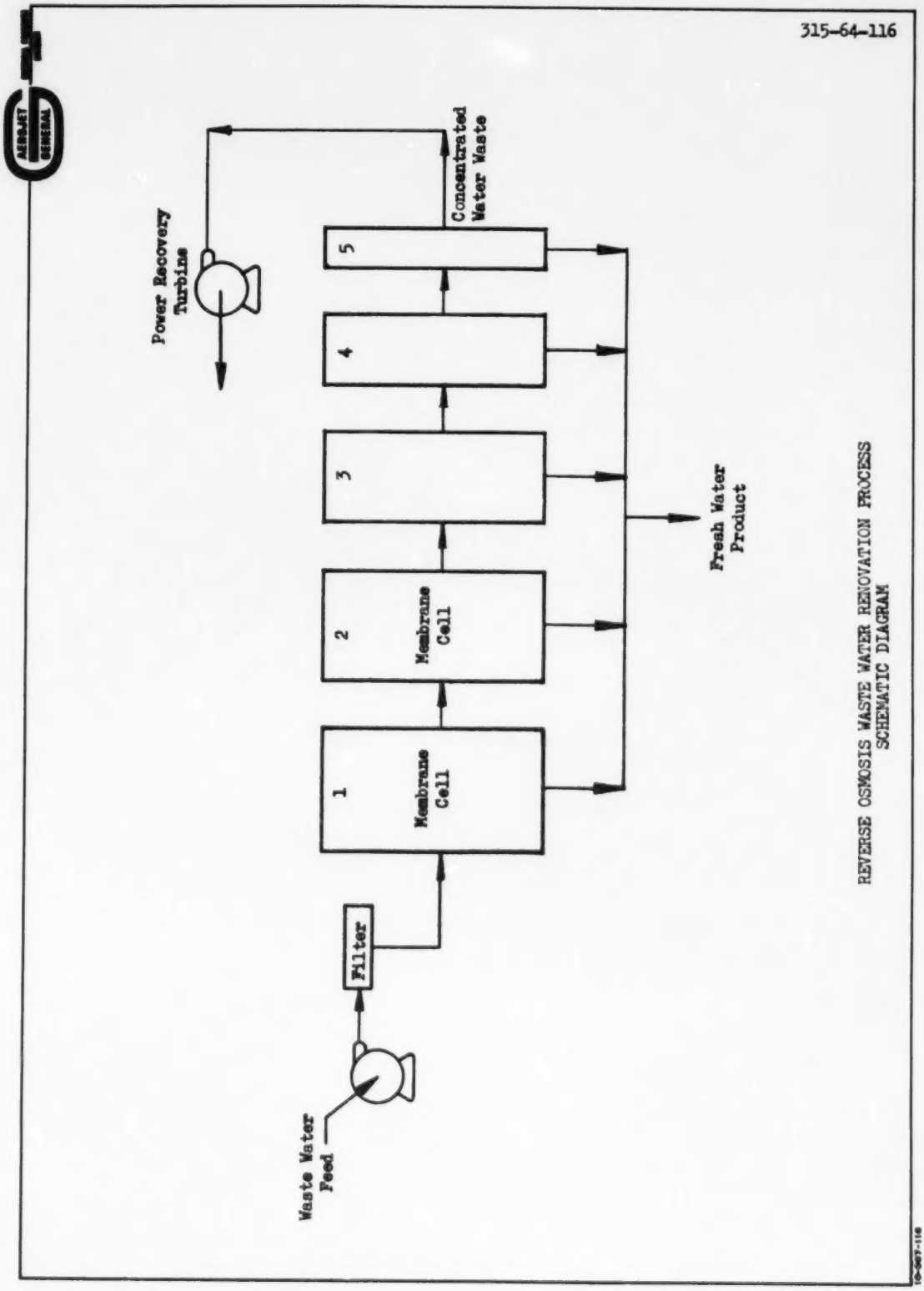
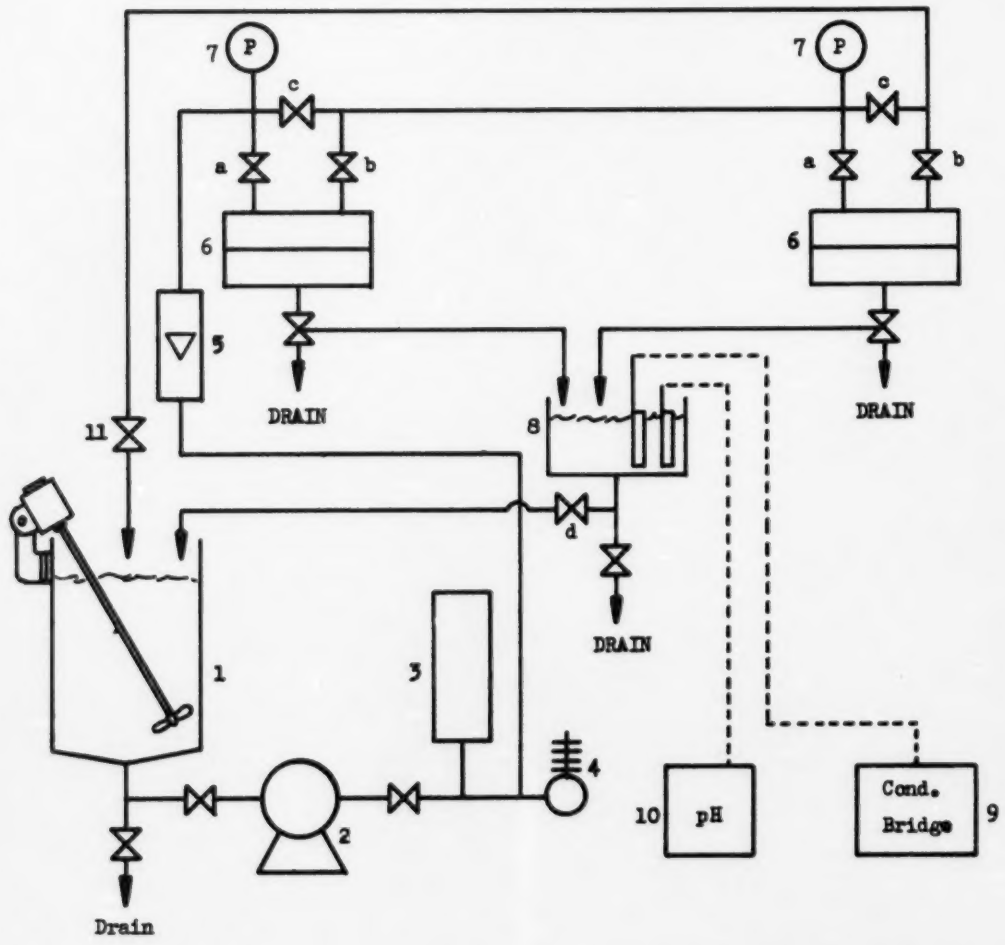

315-64-116
AEROJET GENERAL
Power Recovery Turbine
Concentrated Water Waste
5
4
3
2
Membrane Cell
1
Membrane Cell
Filter
Waste Water Feed
Fresh Water Product
REVERSE OSMOSIS WASTE WATER RENOVATION PROCESS
SCHEMATIC DIAGRAM

Figure 2



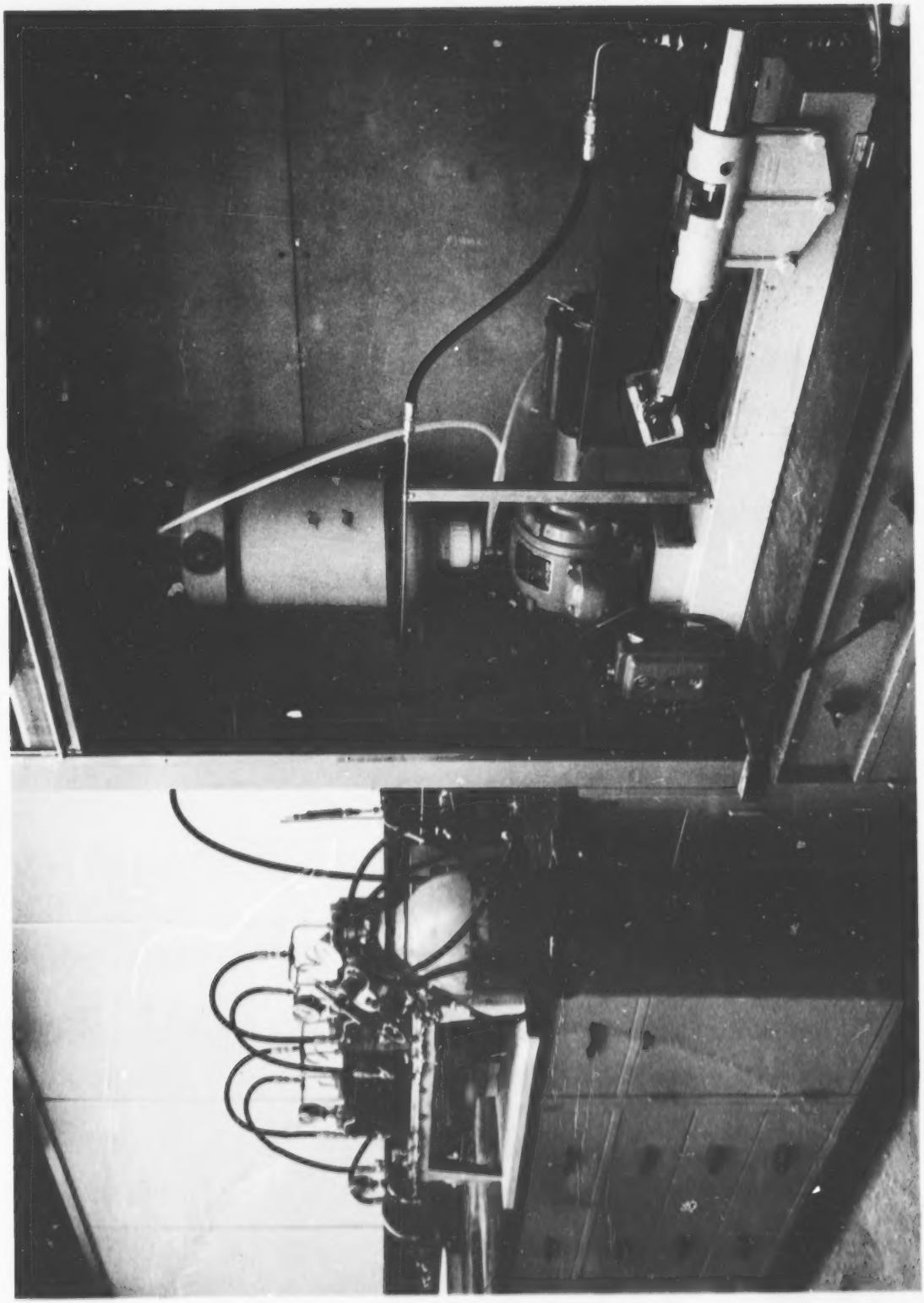
Specific Identification

1. Feed Tank - 5 Gallon Polyethylene
2. Pump - Positive Displacement Jaeco Model 7535-5
3. Accumulator - 1500 psi Nickel Plated
4. Relief Valve - 1600 psi
5. Rotometer - Armored
6. Renovation Cell - 10" dia., Fiber Glass - Epoxy Flanges
7. Pressure Gage - 2000 psi
8. Product Water Receiver
9. Conductivity Cell
10. pH Meter
11. Metering Valve - Fine

315-63-3

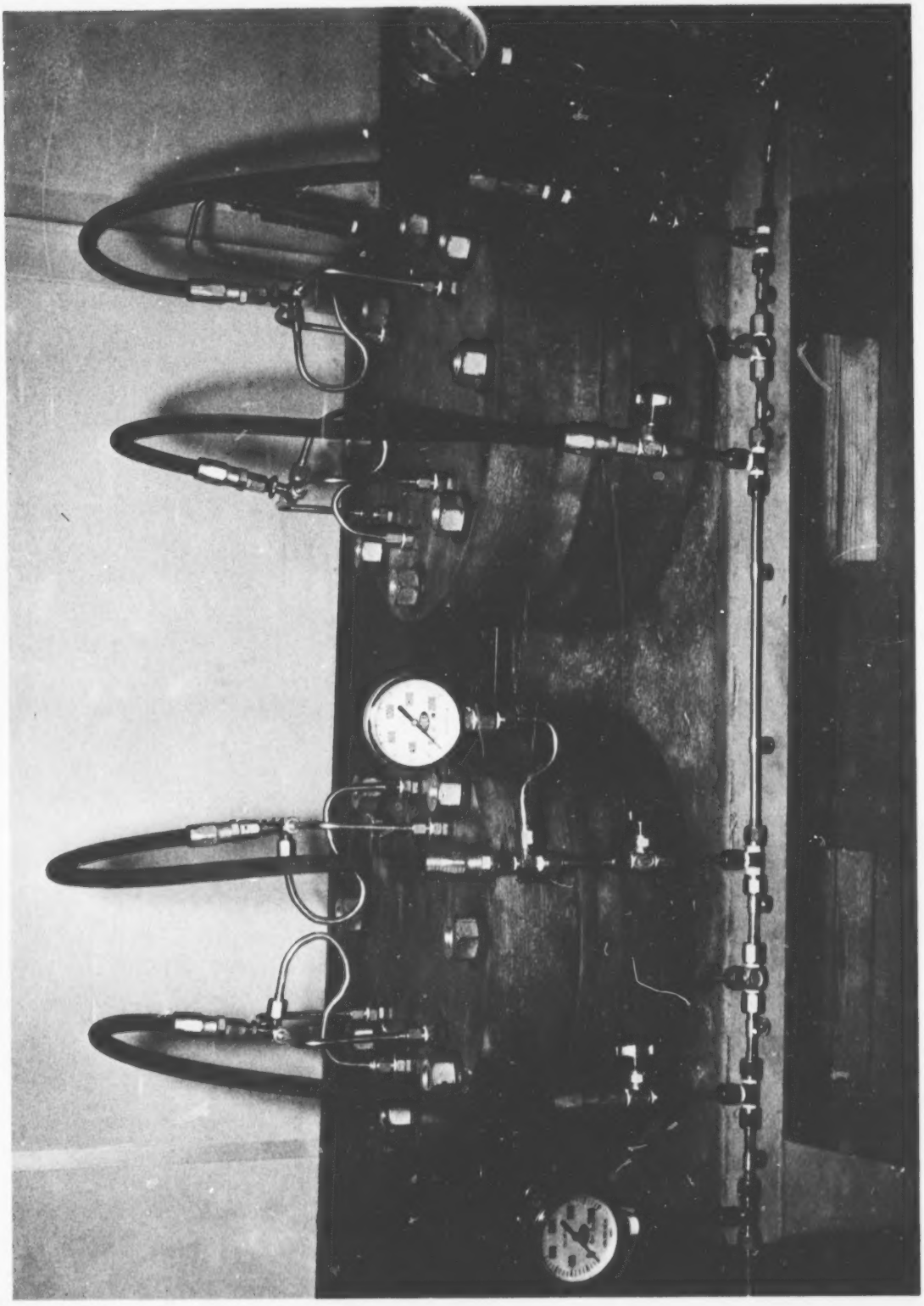
Reverse-Osmosis Apparatus for Waste-Water Treatment

Figure 3



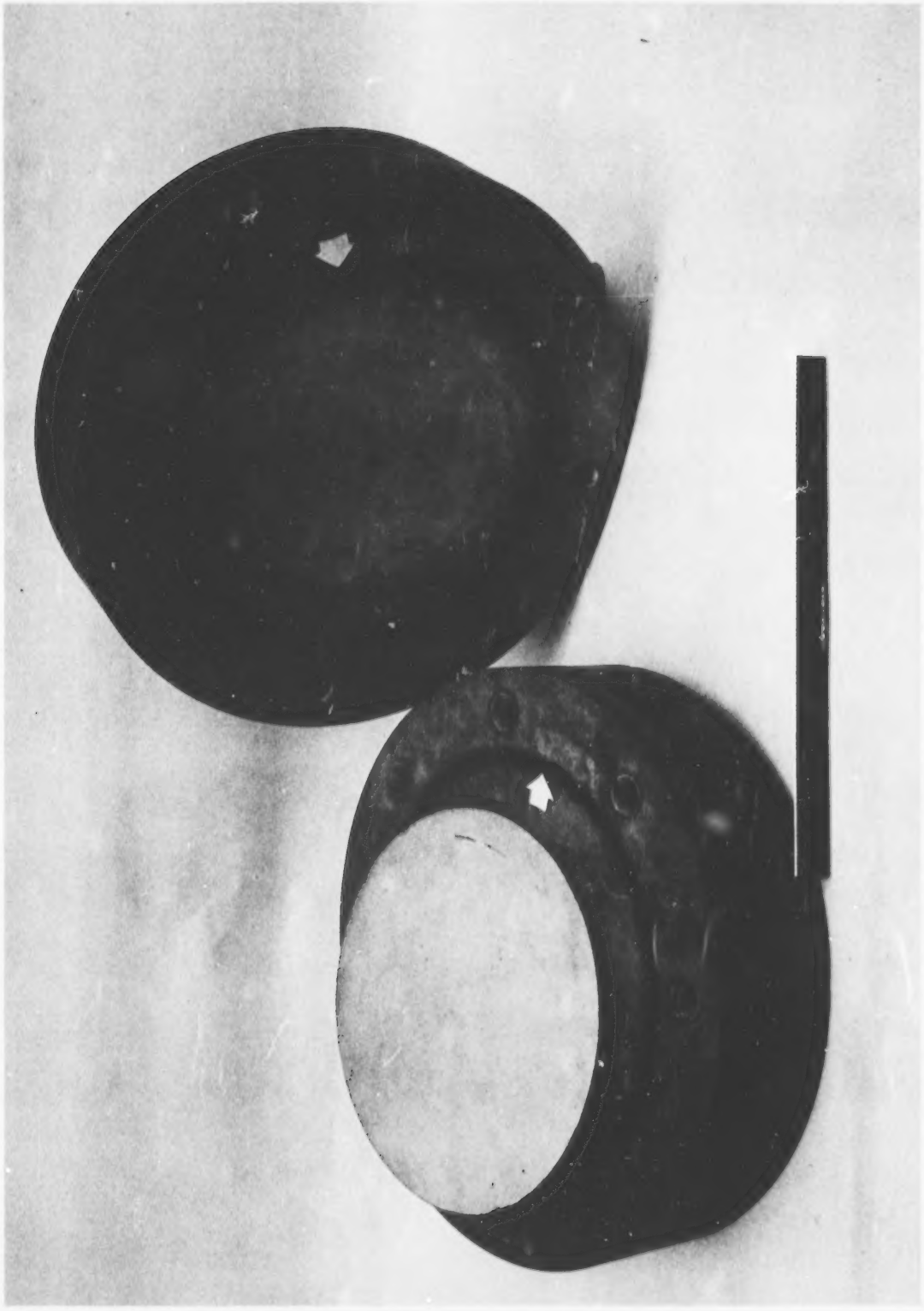
Test Apparatus Overall View

Figure 4



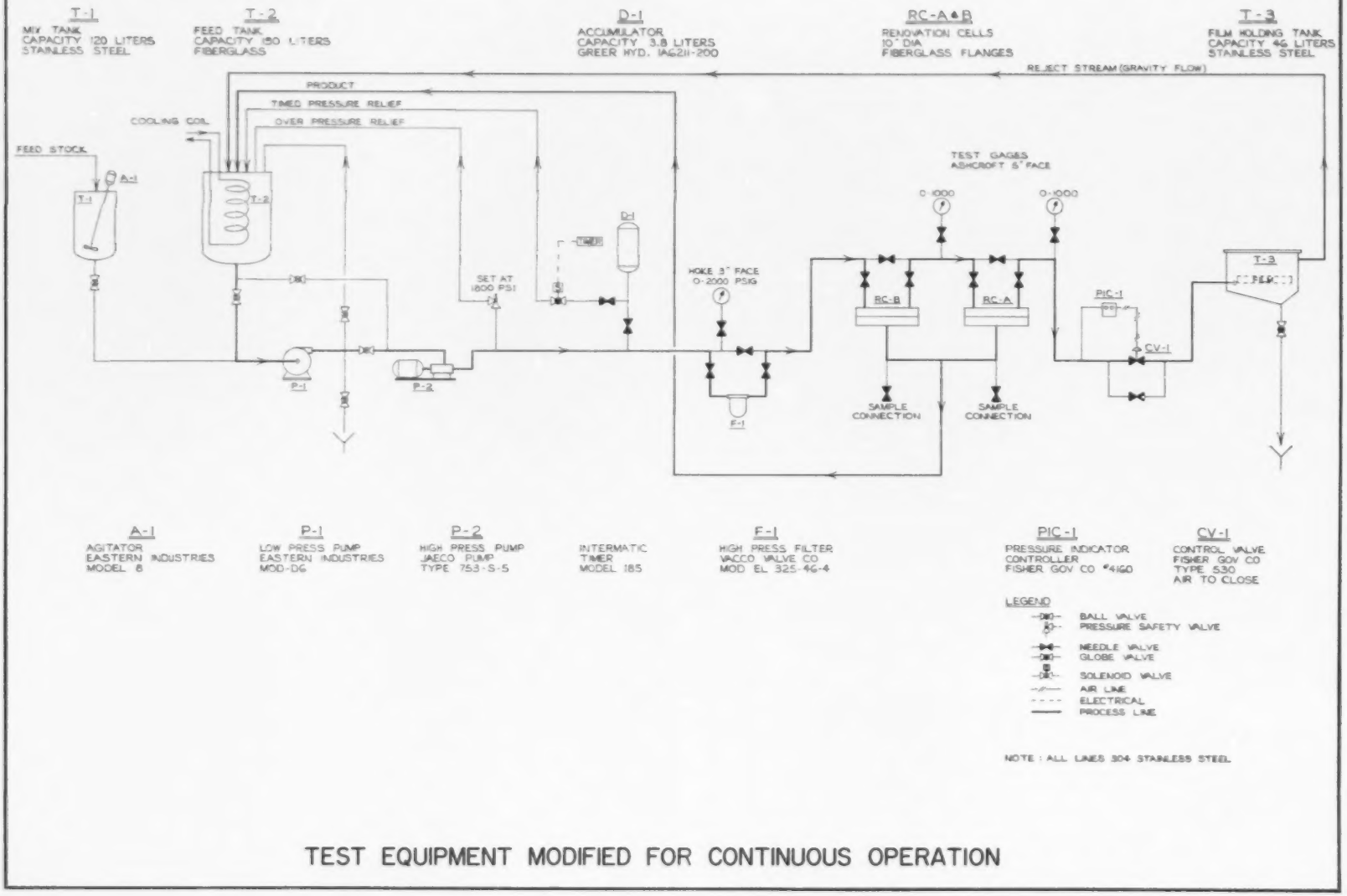
Test Cells, Assembled View

Figure 5



Test Cell, Disassembled Showing "O" Ring Seals

Figure 6



TEST EQUIPMENT MODIFIED FOR CONTINUOUS OPERATION

Figure 7

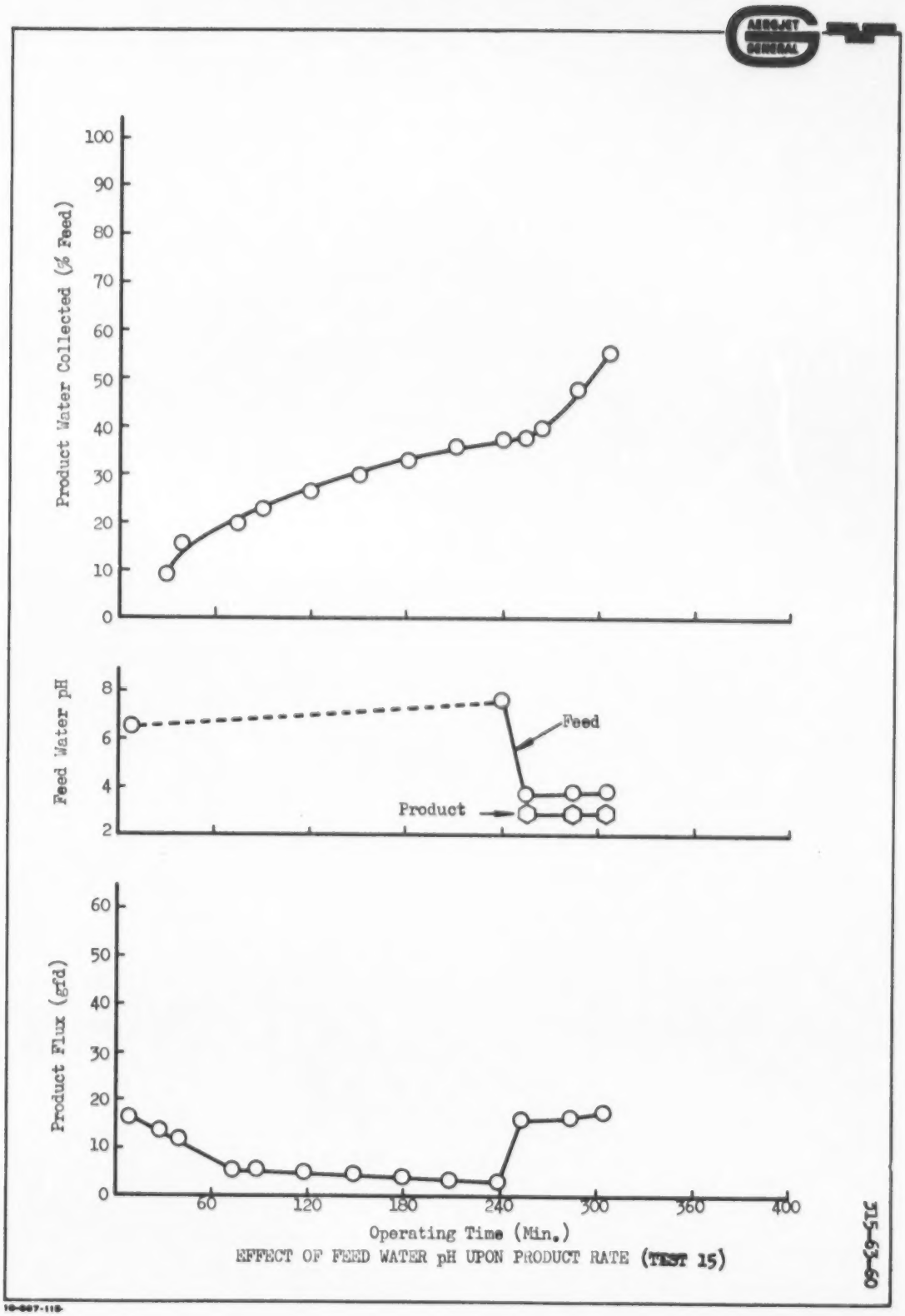
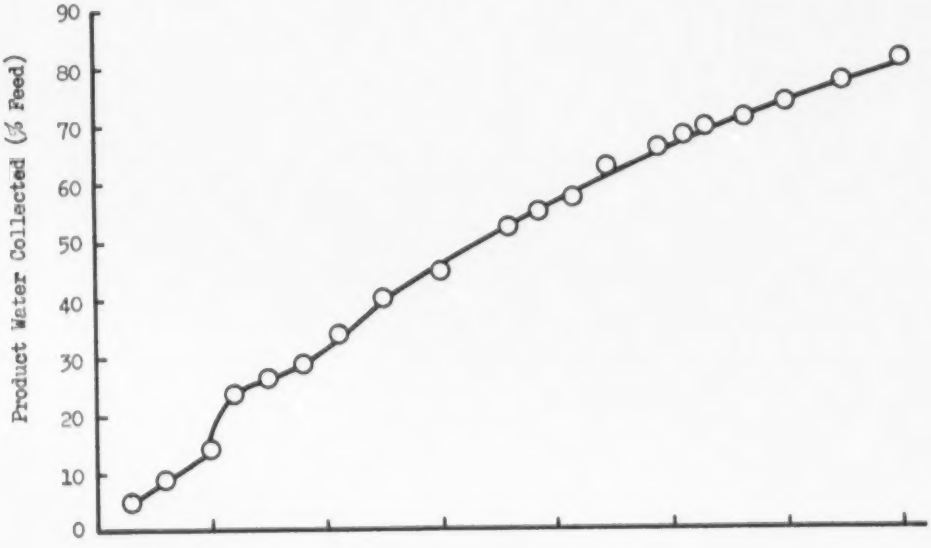
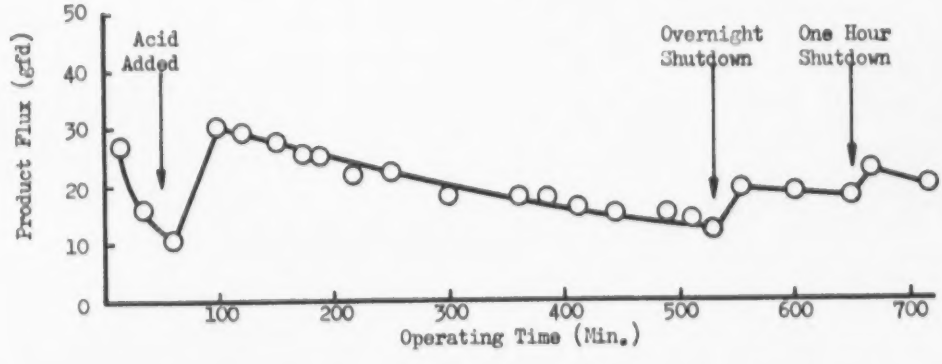

Product Water Collected (% Feed)
100
90
80
70
60
50
40
30
20
10
0
Feed Water pH
8
6
4
2
Feed
Product
Product Flux (gfd)
60
50
40
30
20
10
0
60
120
180
240
300
360
400
Operating Time (Min.)
EFFECT OF FEED WATER pH UPON PRODUCT RATE (TEST 15)
315-63-60

Figure 8



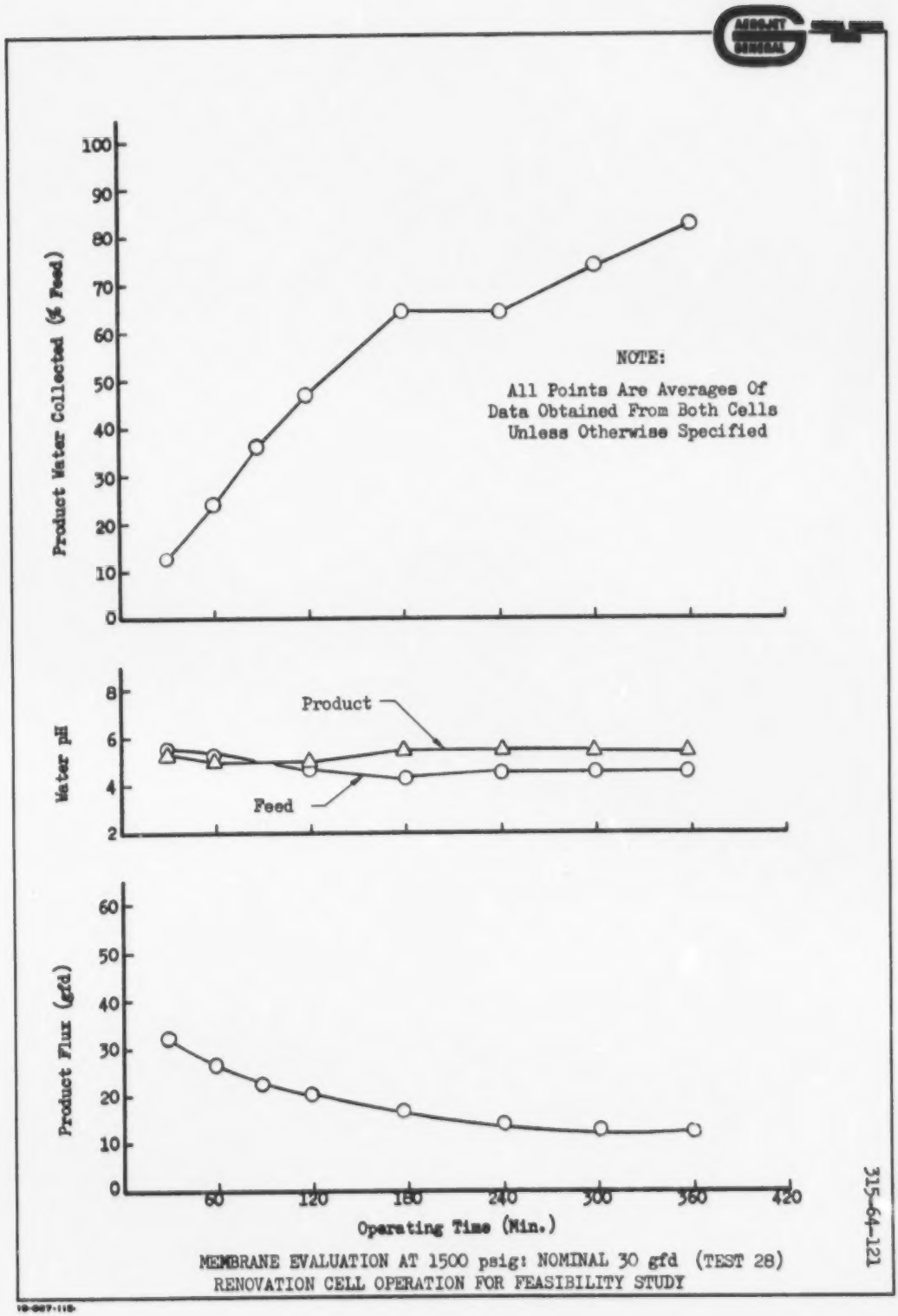
Note:
All points are averages of data obtained from both cells unless otherwise specified



RENOVATION CELL OPERATION FOR FEASIBILITY STUDY (TEST 18)

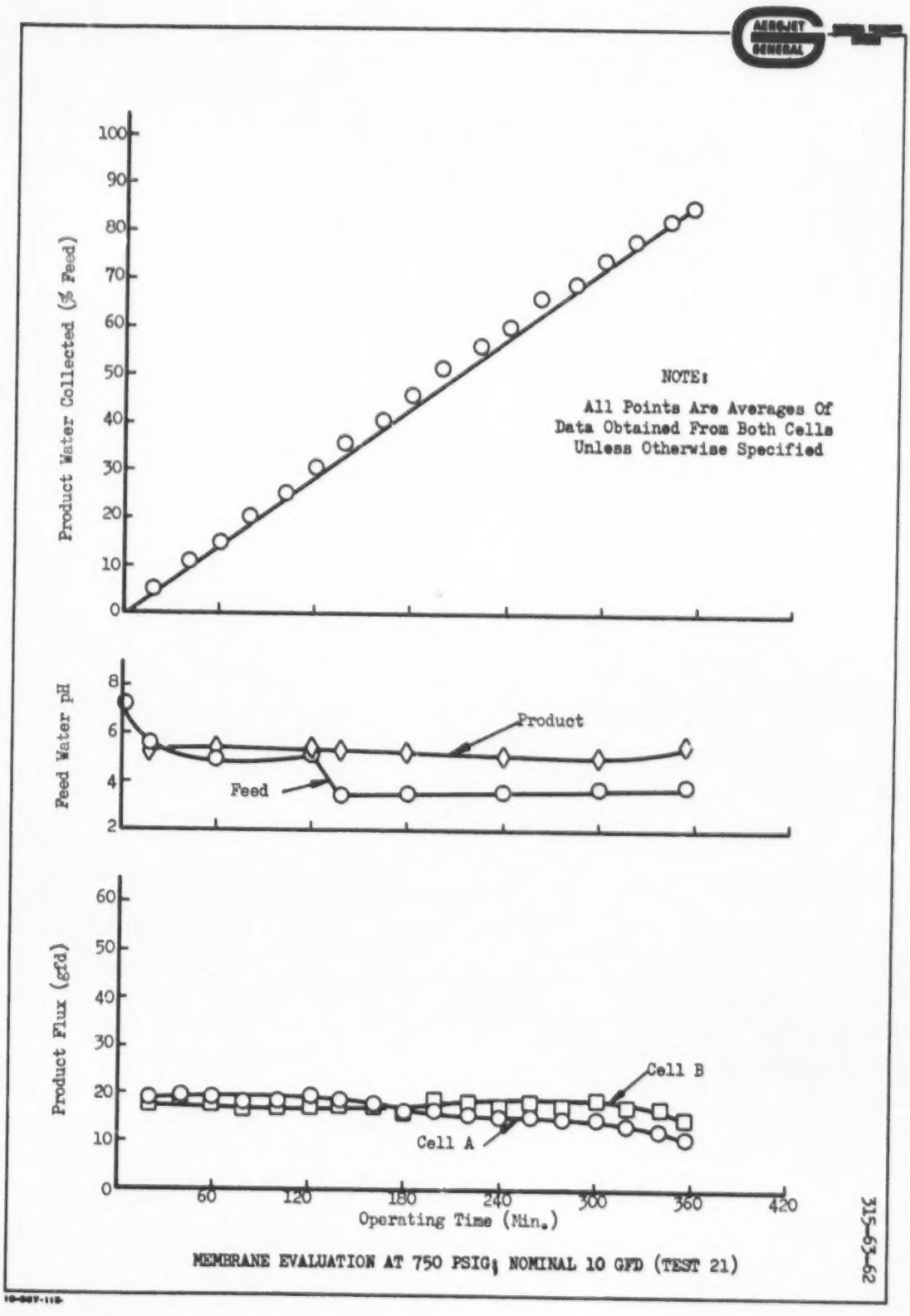
315-63-61

Figure 9



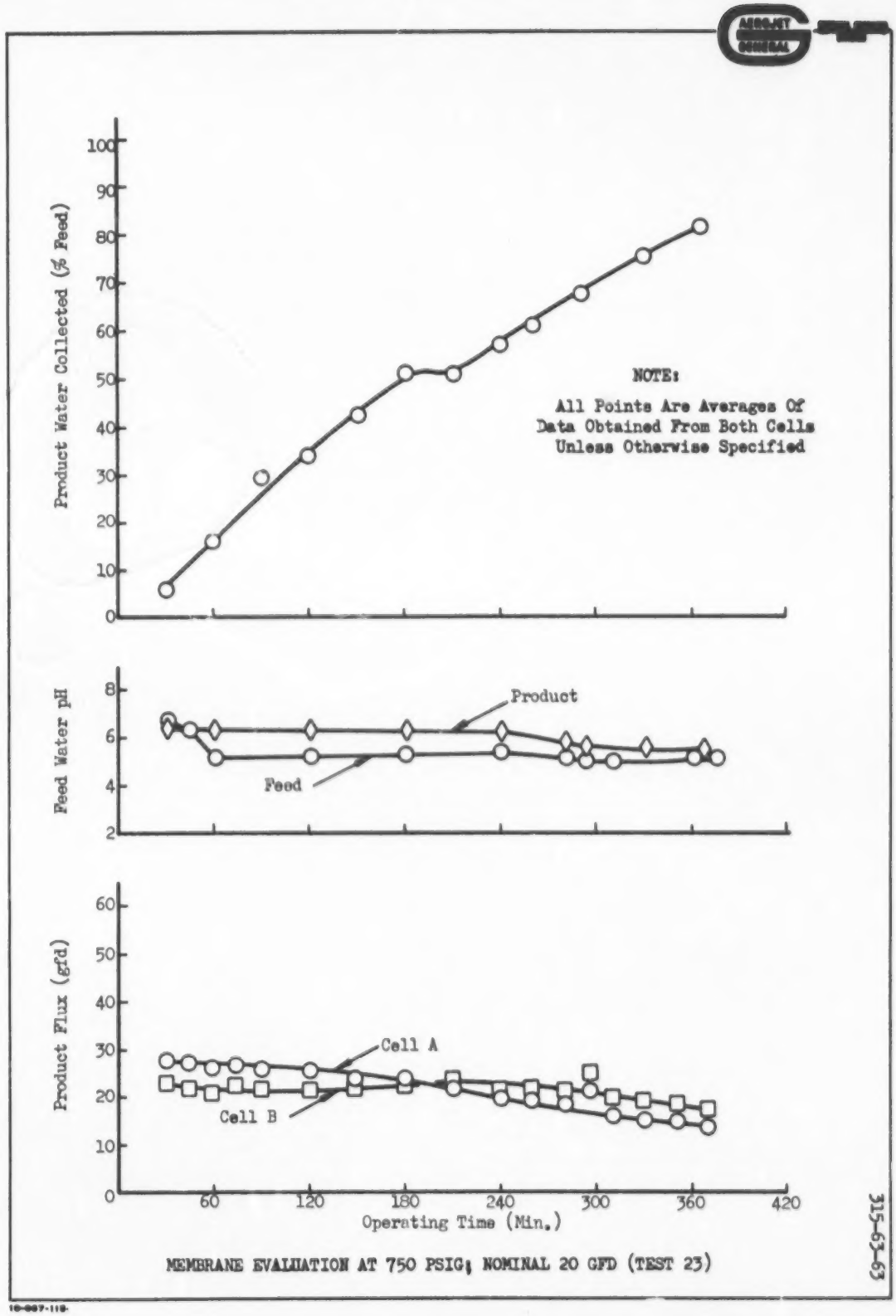
MEMBRANE EVALUATION AT 1500 psig: NOMINAL 30 gfd (TEST 28)
RENOVATION CELL OPERATION FOR FEASIBILITY STUDY

Figure 10



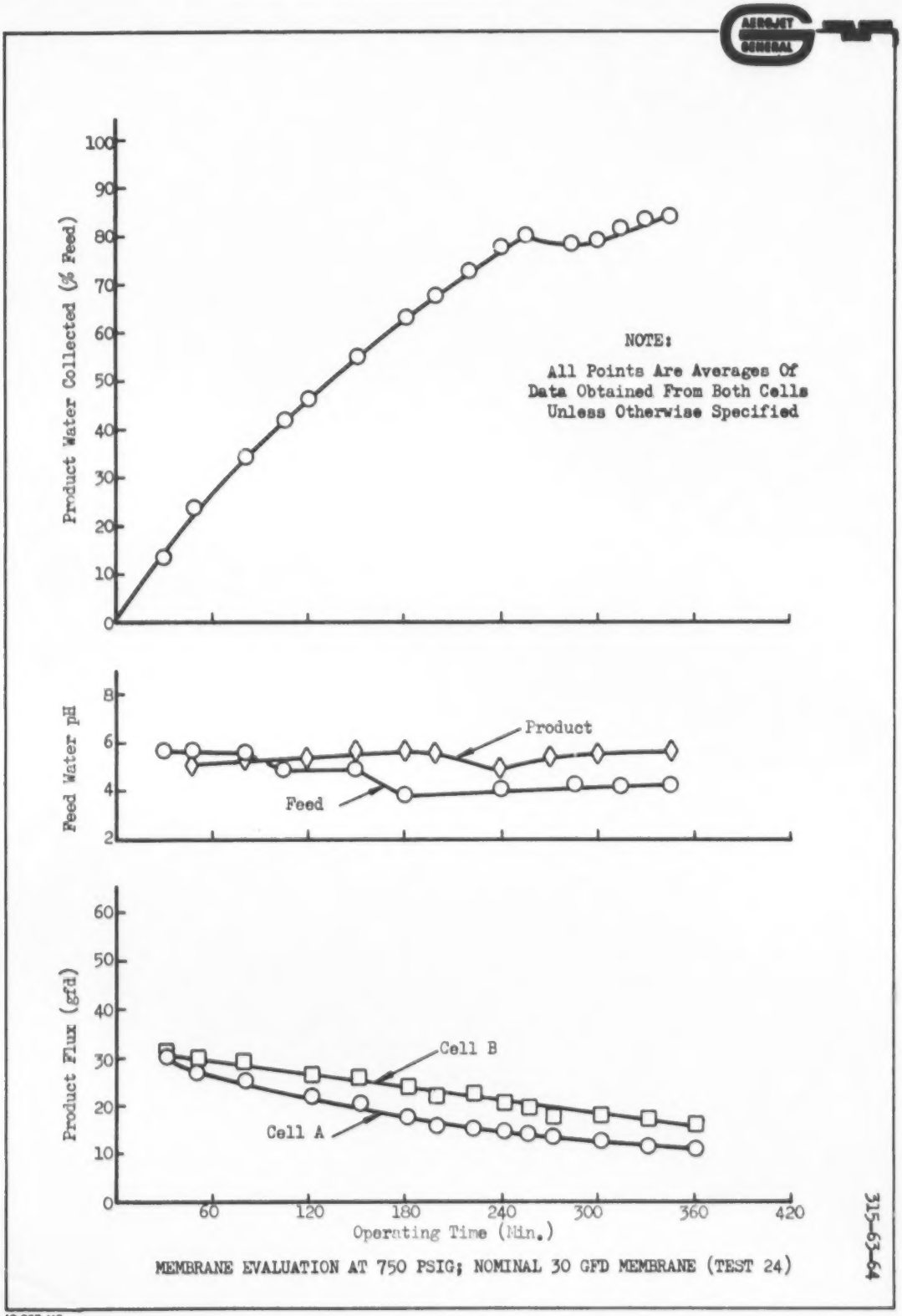
MEMBRANE EVALUATION AT 750 PSIG; NOMINAL 10 GFD (TEST 21)

Figure 11



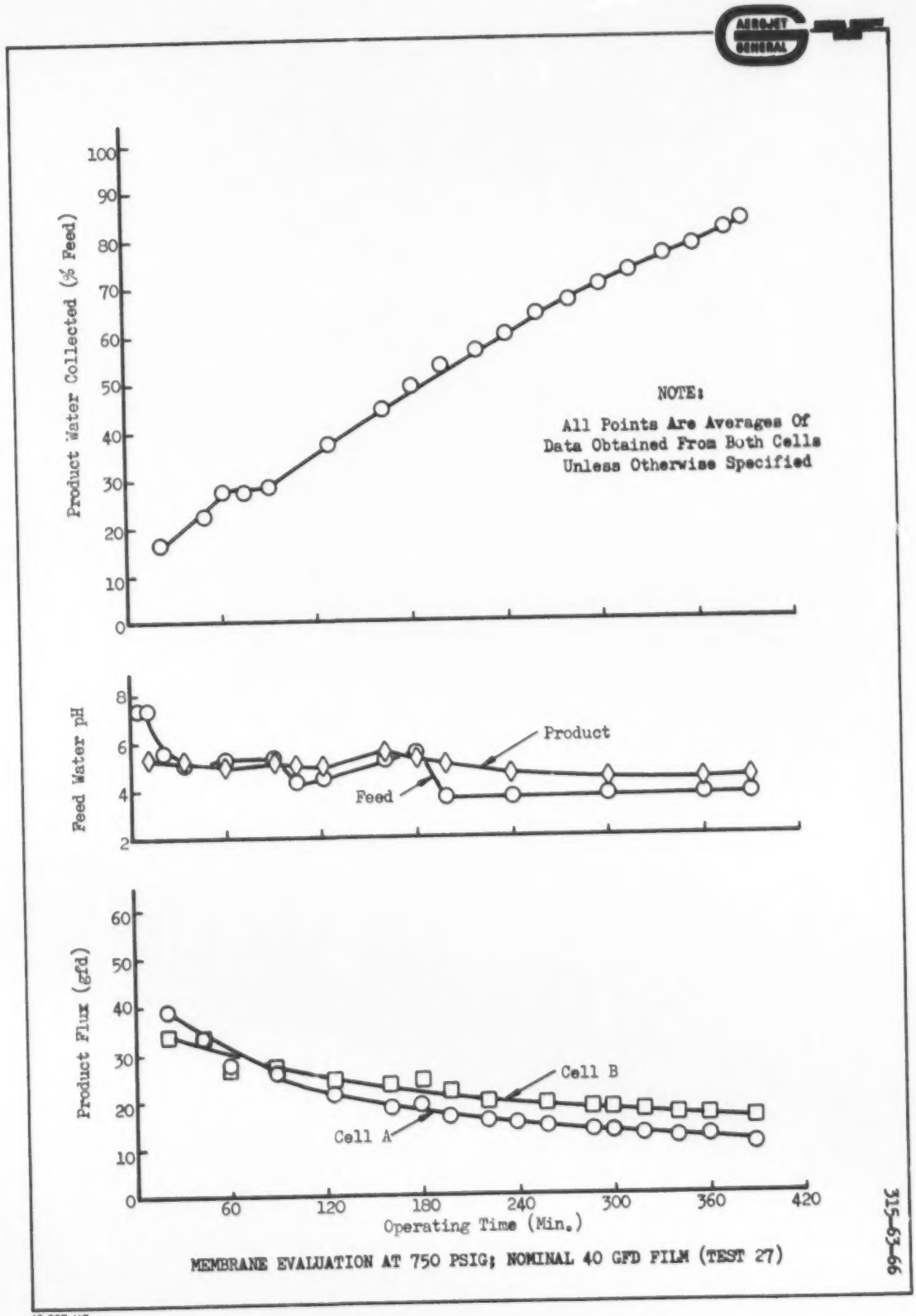
MEMBRANE EVALUATION AT 750 PSIG; NOMINAL 20 GFD (TEST 23)

Figure 12



MEMBRANE EVALUATION AT 750 PSIG; NOMINAL 30 GFD MEMBRANE (TEST 24)

Figure 13



MEMBRANE EVALUATION AT 750 PSIG; NOMINAL 40 GFD FILM (TEST 27)

Figure 14

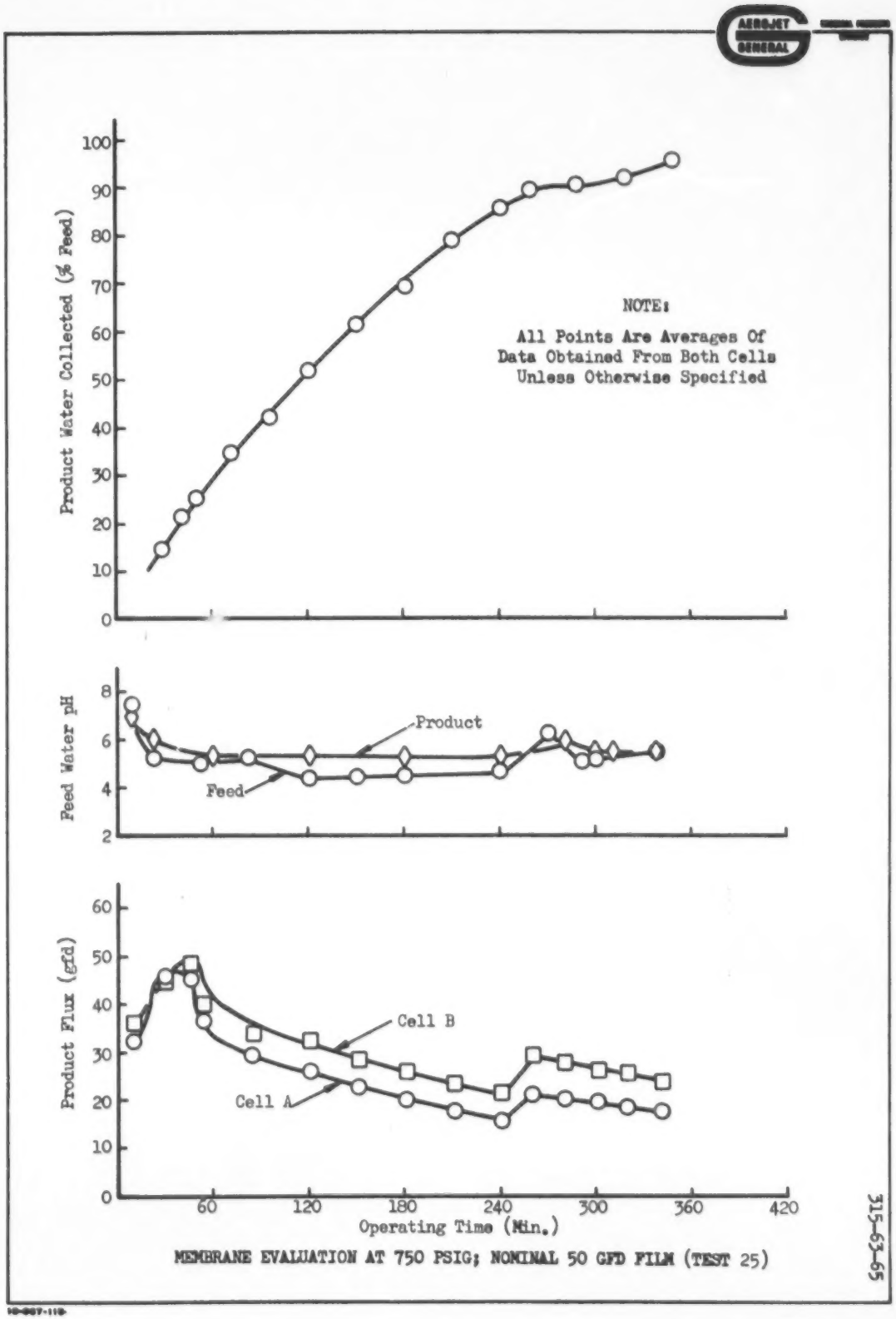

Product Water Collected (% Feed)
100
90
80
70
60
50
40
30
20
10
0
NOTE:
All Points Are Averages Of
Data Obtained From Both Cells
Unless Otherwise Specified
Feed Water pH
8
6
4
2
Product
Feed
Product Flux (gfd)
60
50
40
30
20
10
0
Cell B
Cell A
60
120
180
240
300
360
420
Operating Time (Min.)
MEMBRANE EVALUATION AT 750 PSIG; NOMINAL 50 GFD FILM (TEST 25)
315-63-65

Figure 15

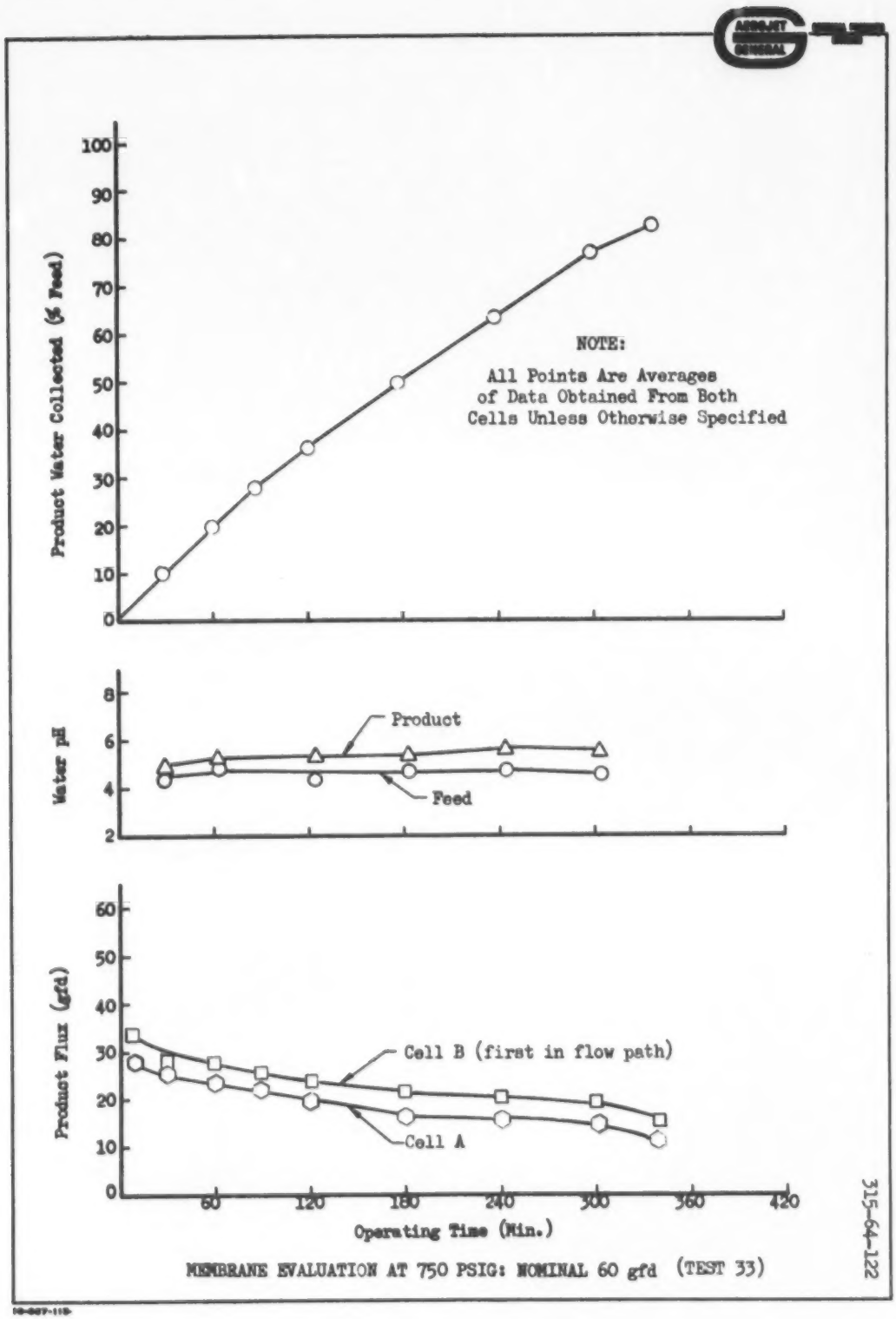

Product Water Collected (% Feed)
100
90
80
70
60
50
40
30
20
10
0
NOTE:
All Points Are Averages
of Data Obtained From Both
Cells Unless Otherwise Specified
Water pH
8
6
4
2
Product
Feed
Product Flux (gfd)
60
50
40
30
20
10
0
Cell B (first in flow path)
Cell A
60
120
180
240
300
360
420
Operating Time (Min.)
MEMBRANE EVALUATION AT 750 PSIG: NOMINAL 60 gfd (TEST 33)
315-64-122

Figure 16

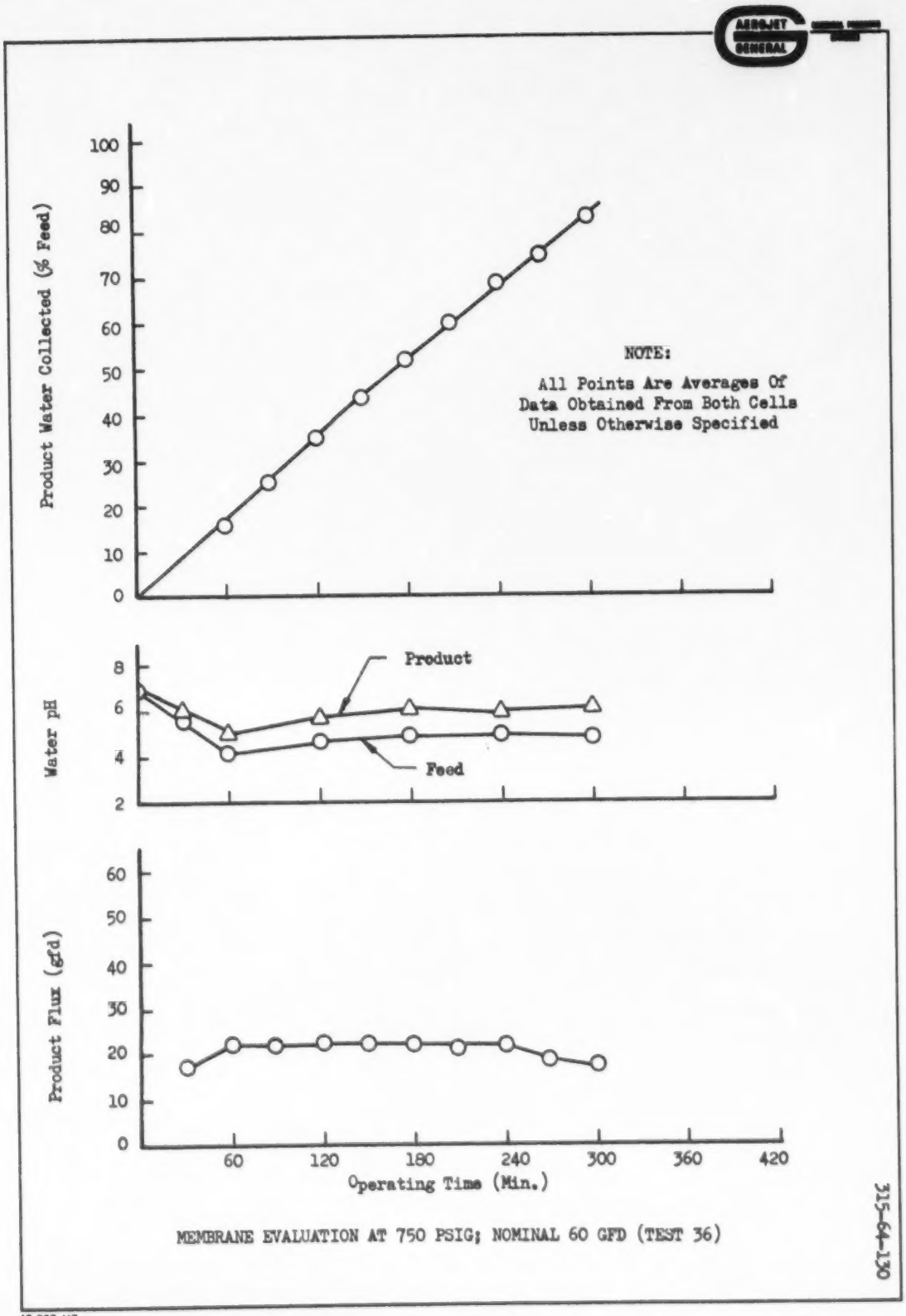

Product Water Collected (% Feed)
100
90
80
70
60
50
40
30
20
10
0
NOTE:
All Points Are Averages Of
Data Obtained From Both Cells
Unless Otherwise Specified
Water pH
8
6
4
2
Product
Feed
Product Flux (gfd)
60
50
40
30
20
10
0
60
120
180
240
300
360
420
Operating Time (Min.)
MEMBRANE EVALUATION AT 750 PSIG; NOMINAL 60 GFD (TEST 36)
315-64-130

Figure 17

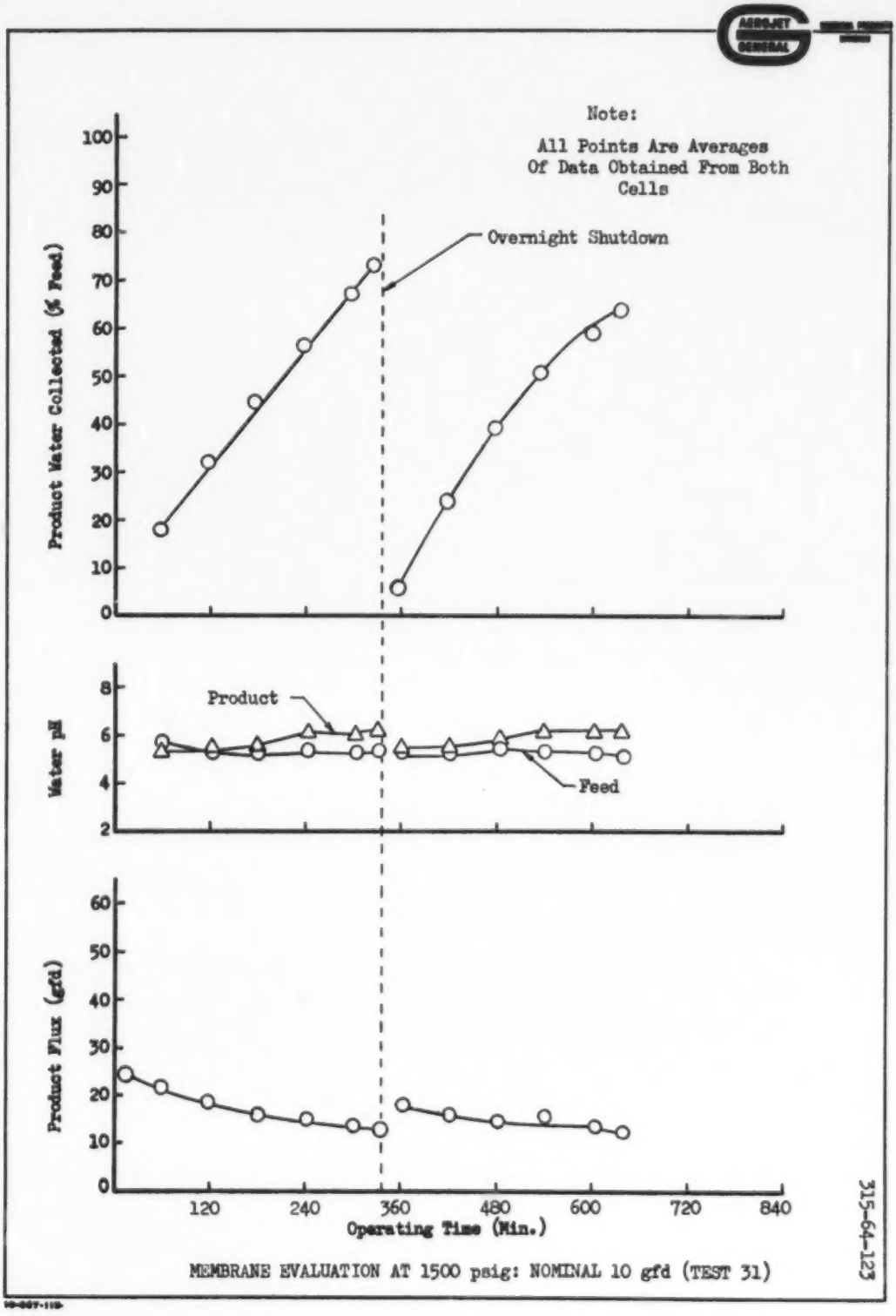
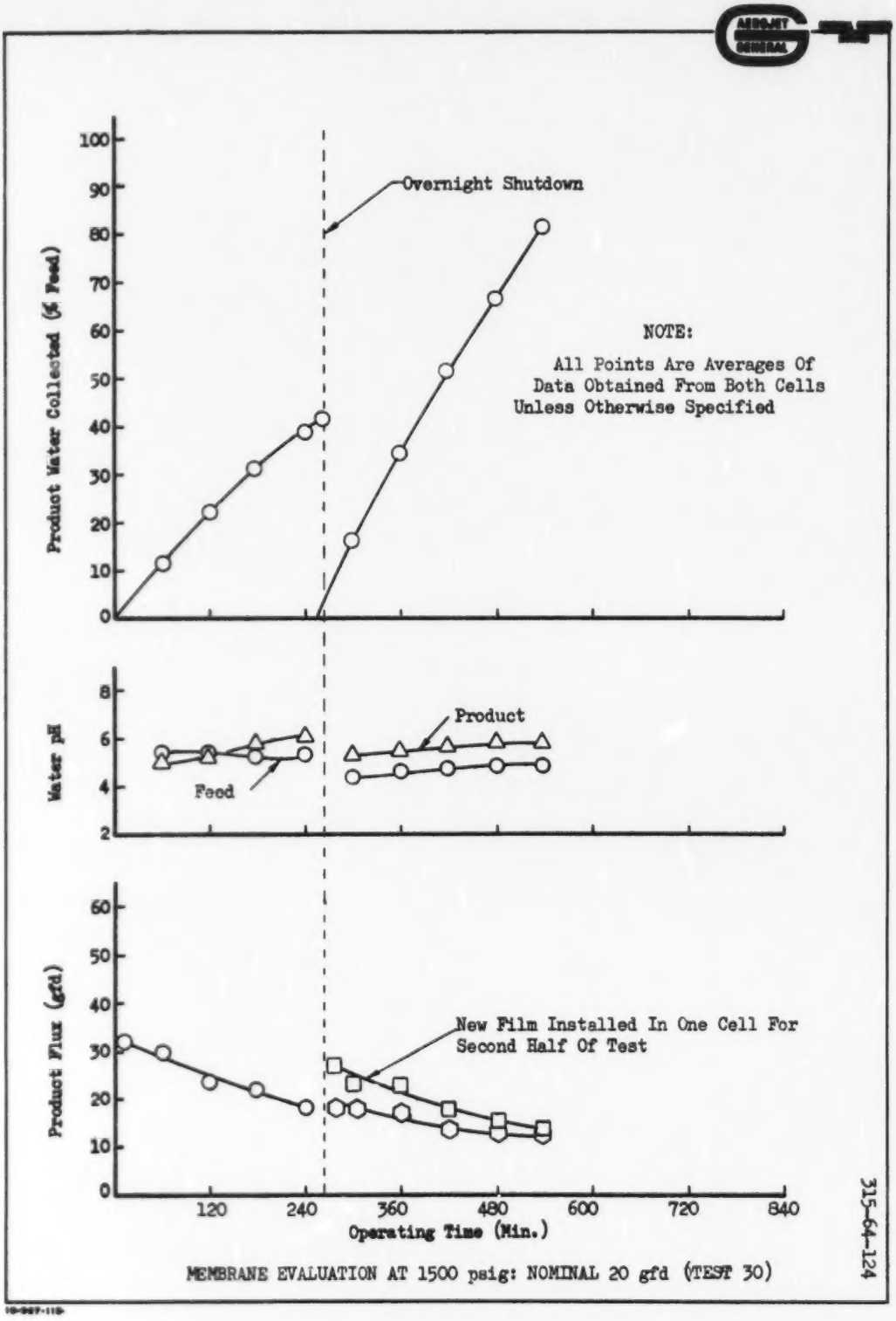

Note:
All Points Are Averages
Of Data Obtained From Both
Cells
Overnight Shutdown
Product Water Collected (% Feed)
100
90
80
70
60
50
40
30
20
10
0
Product
Feed
Water pH
8
6
4
2
Product Flux (gfd)
60
50
40
30
20
10
0
120
240
360
480
600
720
840
Operating Time (Min.)
MEMBRANE EVALUATION AT 1500 psig: NOMINAL 10 gfd (TEST 31)
315-64-123

Figure 18



MEMBRANE EVALUATION AT 1500 psig: NOMINAL 20 gfd (TEST 30)

Figure 19

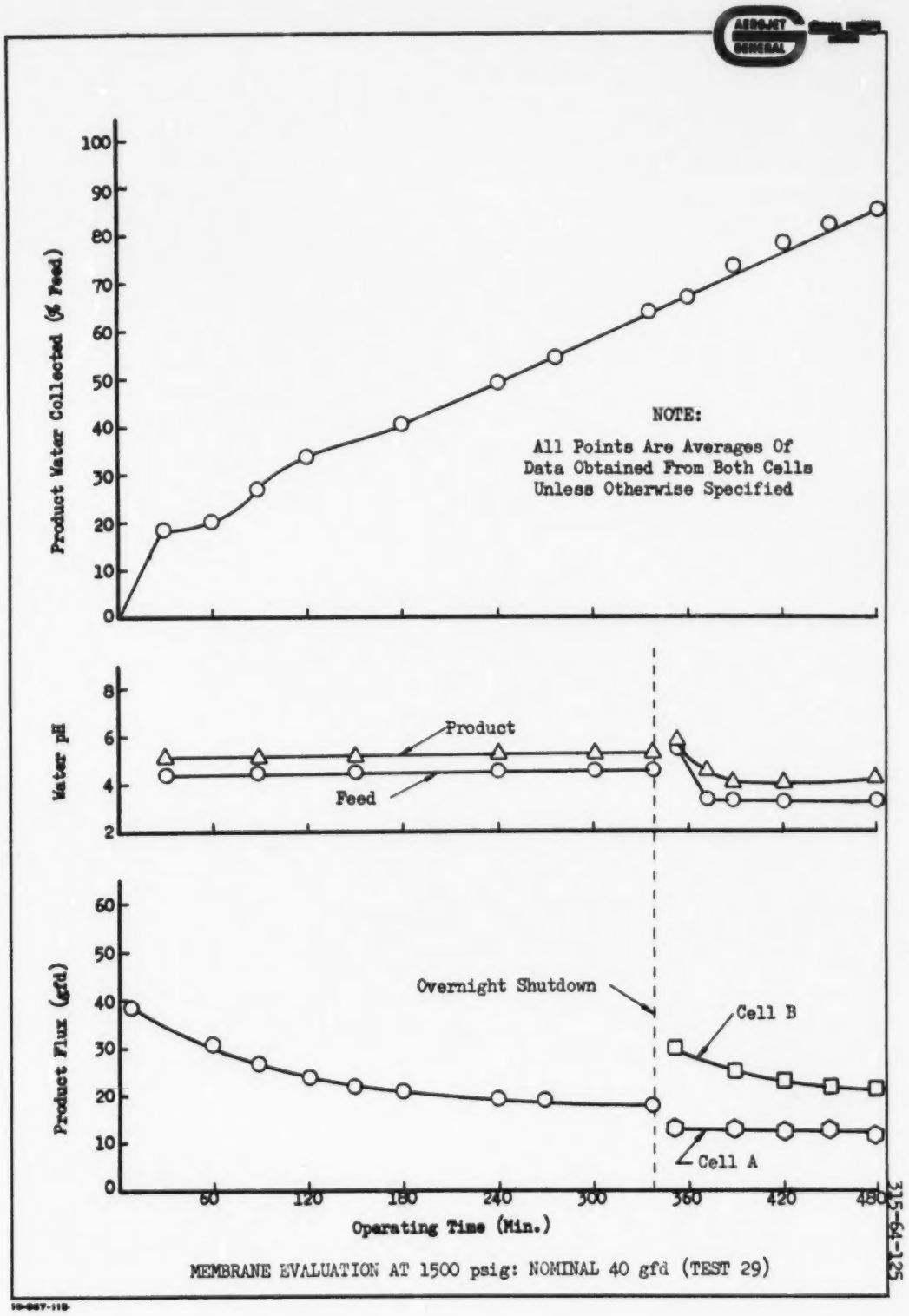
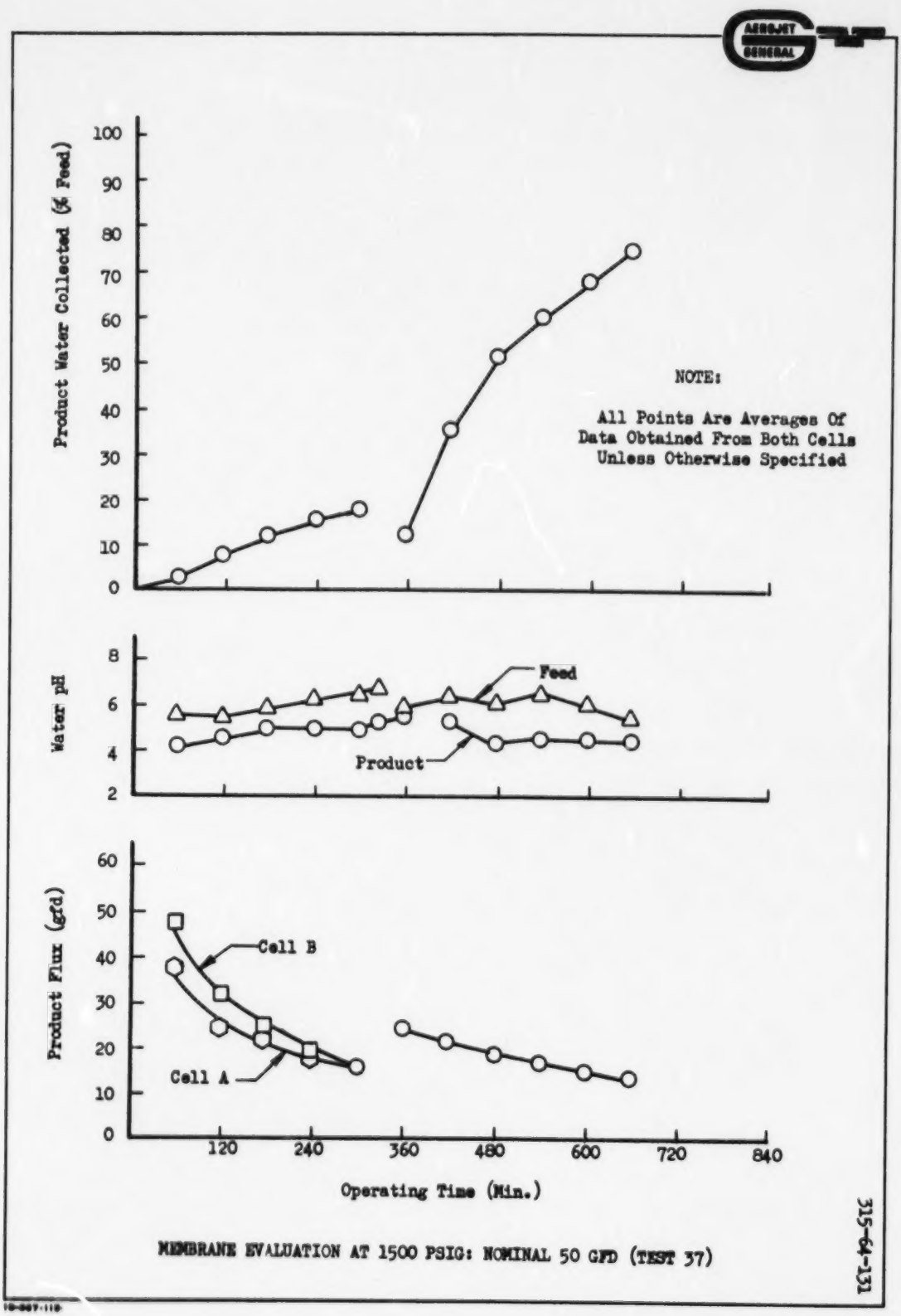

Product Water Collected (% Feed)
100
90
80
70
60
50
40
30
20
10
0
NOTE:
All Points Are Averages Of
Data Obtained From Both Cells
Unless Otherwise Specified
Water pH
8
6
4
2
Product
Feed
Product Flux (gfd)
60
50
40
30
20
10
0
Overnight Shutdown
Cell B
Cell A
60
120
180
240
300
360
420
480
Operating Time (Min.)
315-64-125
MEMBRANE EVALUATION AT 1500 psig: NOMINAL 40 gfd (TEST 29)

Figure 20



MEMBRANE EVALUATION AT 1500 PSIG: NOMINAL 50 GFD (TEST 37)

Figure 21

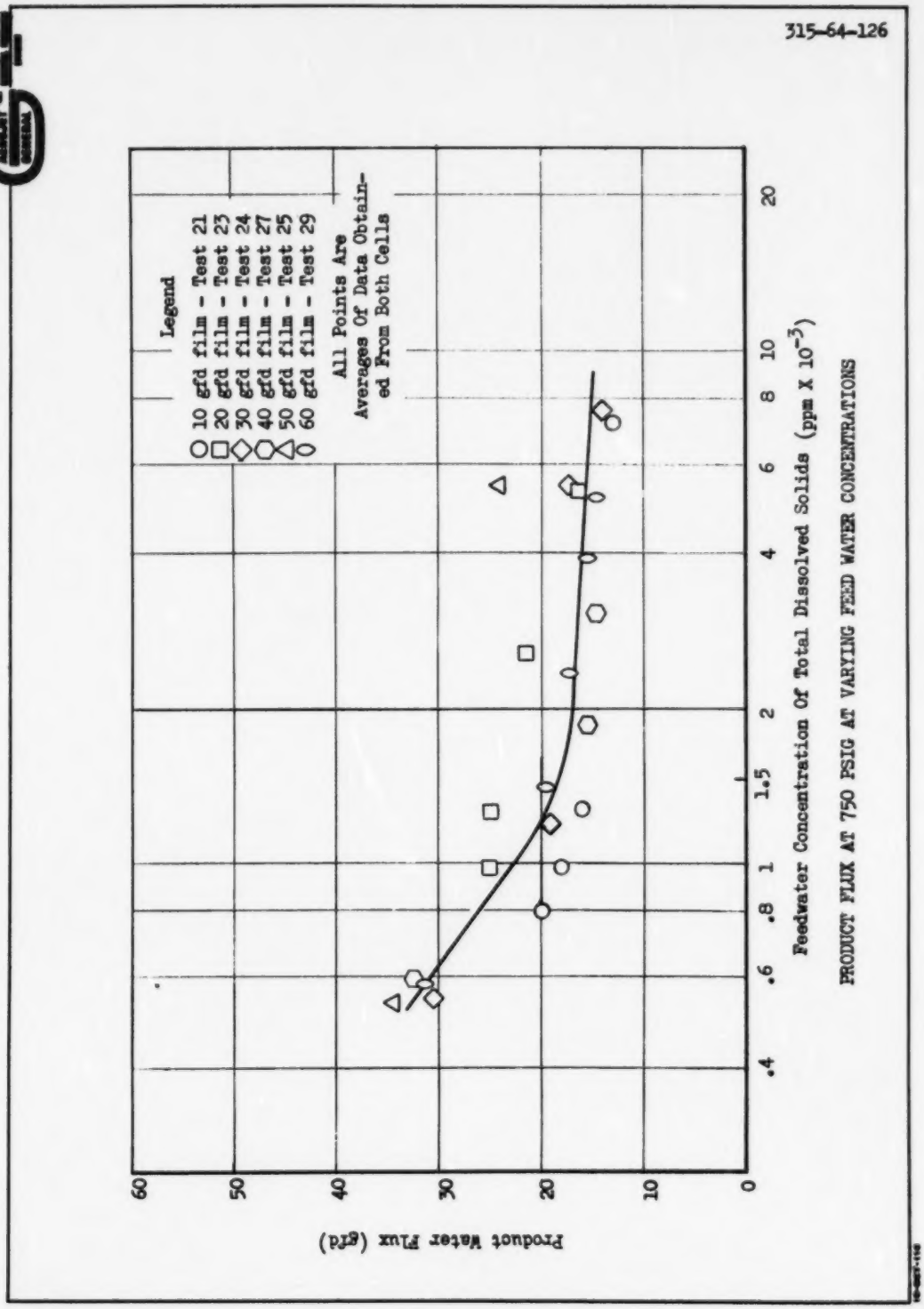

315-64-126
Legend
10 gfd film - Test 21
20 gfd film - Test 23
30 gfd film - Test 24
40 gfd film - Test 27
50 gfd film - Test 25
60 gfd film - Test 29
All Points Are Averages Of Data Obtained From Both Cells
Product Water Flux (gfd)
0
10
20
30
40
50
60
.4
.6
.8
1
1.5
2
4
6
8
10
20
Feedwater Concentration Of Total Dissolved Solids (ppm X 10^{-3})
PRODUCT FLUX AT 750 PSIG AT VARYING FEED WATER CONCENTRATIONS

Figure 22

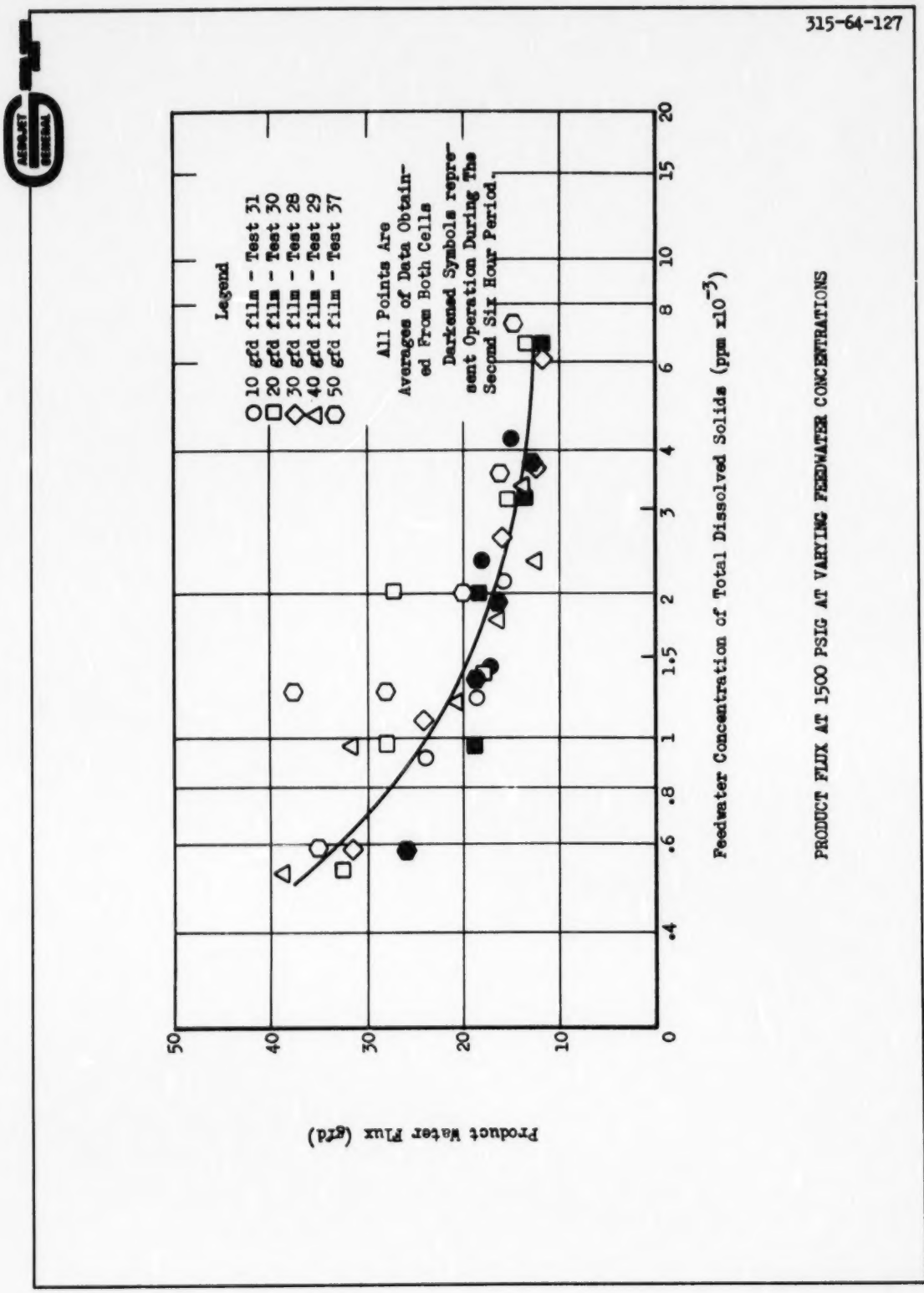
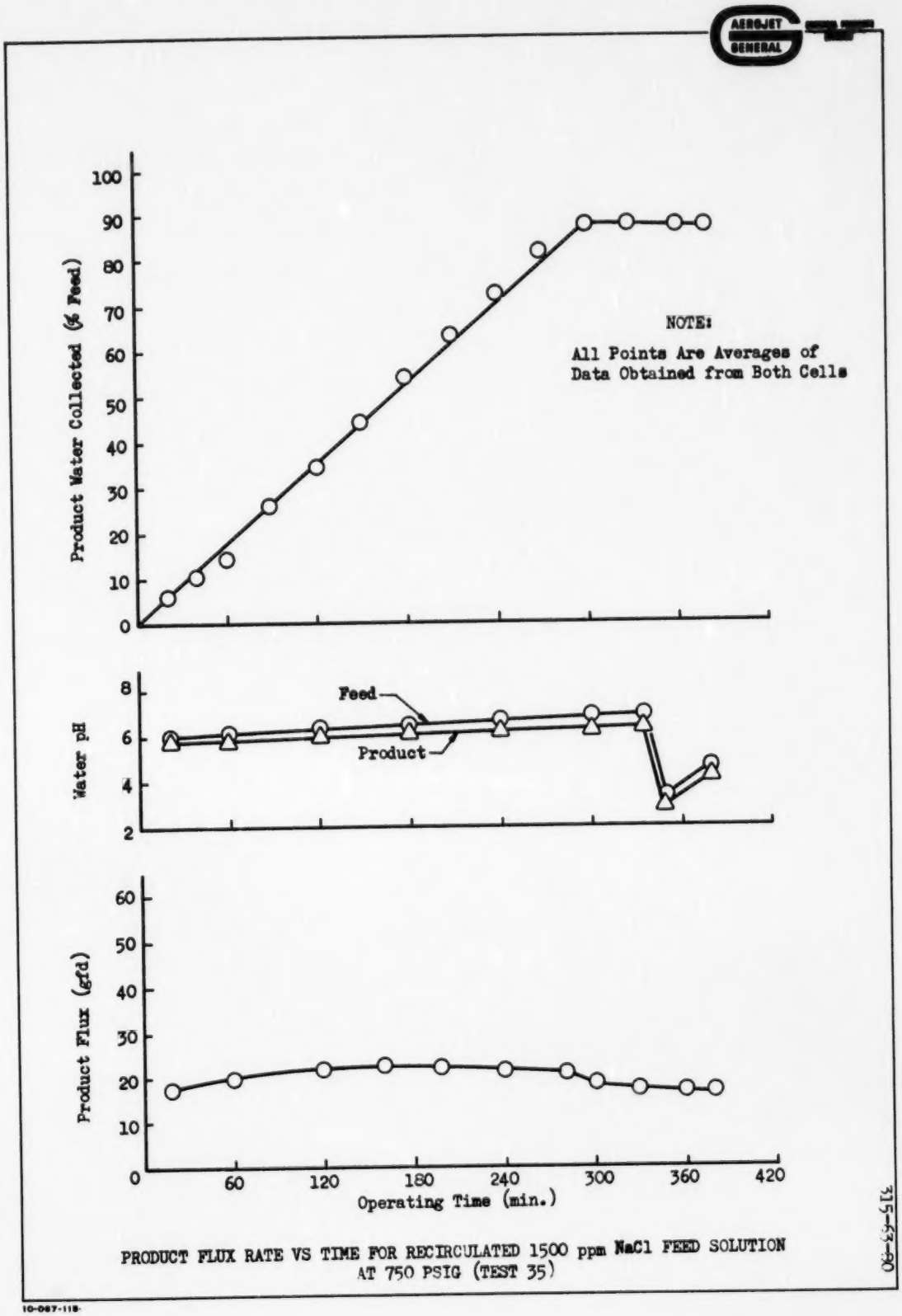

315-64-127
Legend
10 gfd film - Test 31
20 gfd film - Test 30
30 gfd film - Test 28
40 gfd film - Test 29
50 gfd film - Test 37
All Points Are Averages of Data Obtained From Both Cells
Darkened Symbols represent Operation During The Second Six Hour Period.
Product Water Flux (gfd)
50
40
30
20
10
0
.4
.6
.8
1
1.5
2
3
4
6
8
10
15
20
Feedwater Concentration of Total Dissolved Solids (ppm x10^{-3})
PRODUCT FLUX AT 1500 PSIG AT VARYING FEEDWATER CONCENTRATIONS

Figure 23



PRODUCT FLUX RATE VS TIME FOR RECIRCULATED 1500 ppm NaCl FEED SOLUTION AT 750 PSIG (TEST 35)

Figure 24

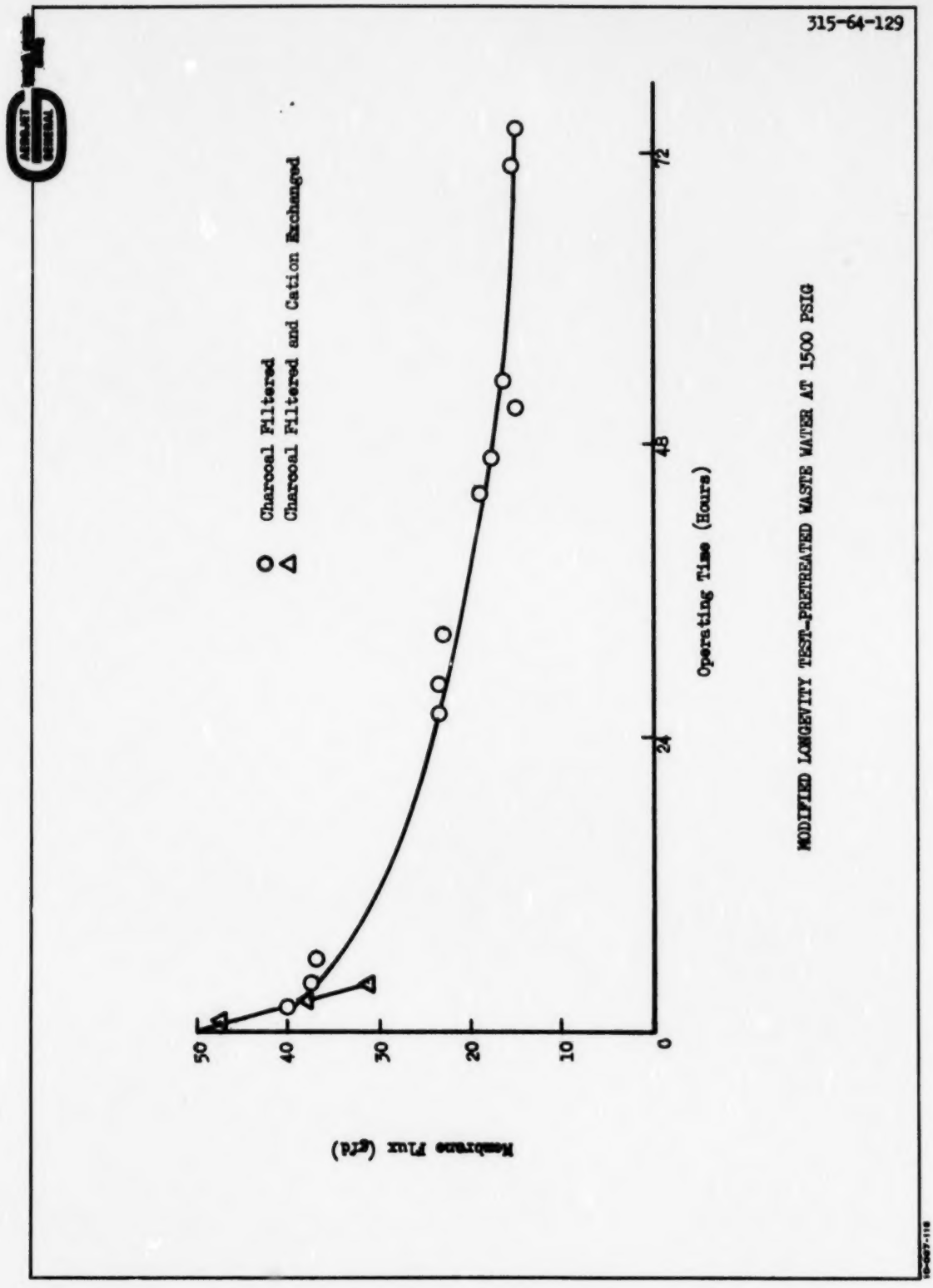

315-64-129
Membrane Flux (gfd)
50
40
30
20
10
0
24
48
72
Operating Time (Hours)
Charcoal Filtered
Charcoal Filtered and Cation Exchanged
MODIFIED LONGEVITY TEST-PRETREATED WASTE WATER AT 1500 PSIG

Figure 25

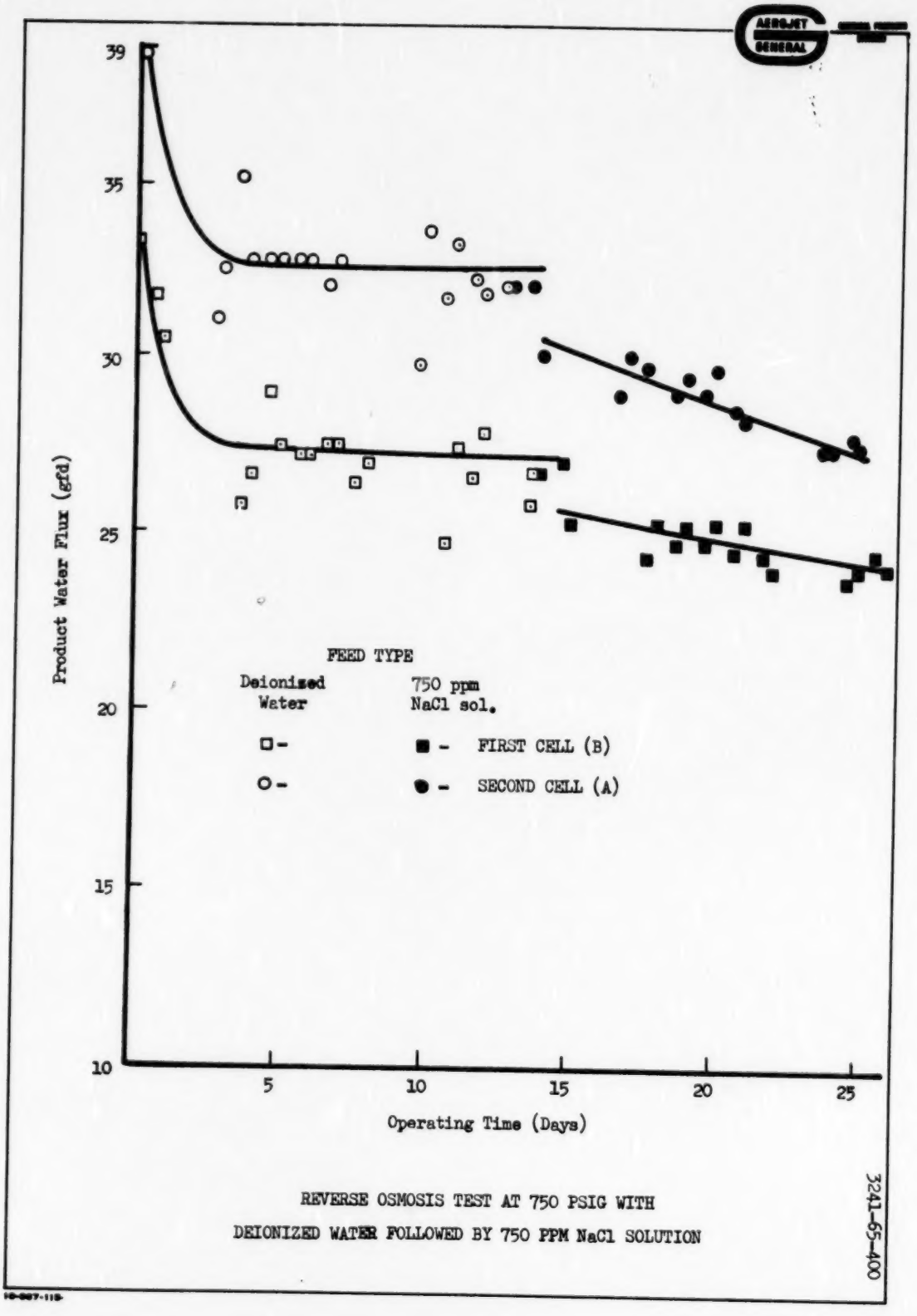

AEROJET GENERAL
Product Water Flux (gfd)
39
35
30
25
20
15
10
5
10
15
20
25
Operating Time (Days)
FEED TYPE
Deionized Water
750 ppm NaCl sol.
□ - ■ - FIRST CELL (B)
○ - ● - SECOND CELL (A)
REVERSE OSMOSIS TEST AT 750 PSIG WITH
DEIONIZED WATER FOLLOWED BY 750 PPM NaCl SOLUTION
3241-65-400

Figure 26

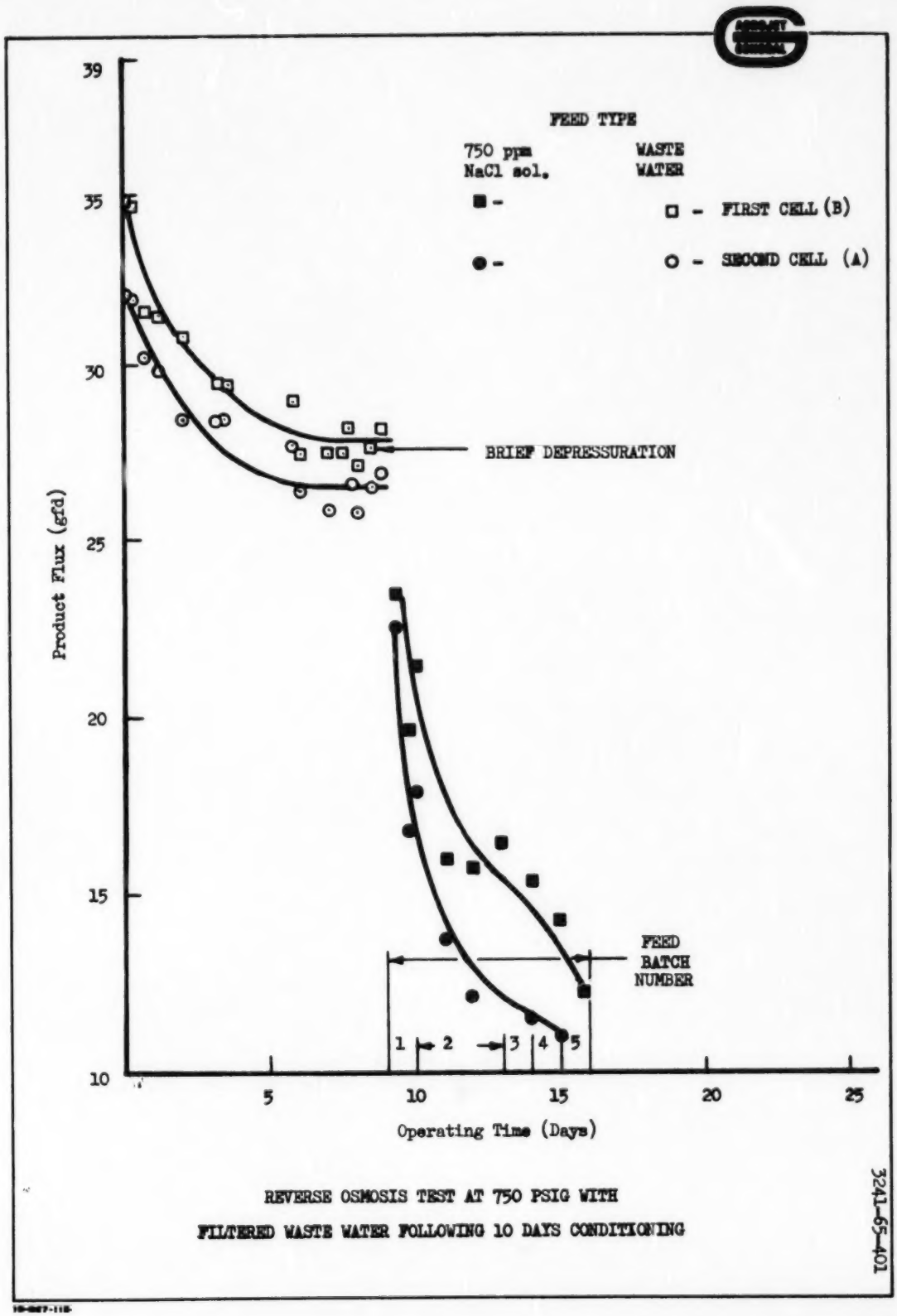

FEED TYPE
750 ppm NaCl sol.
WASTE WATER
■ - □ - FIRST CELL (B)
● - ○ - SECOND CELL (A)
BRIEF DEPRESSURATION
FEED BATCH NUMBER
1
2
3
4
5
Product Flux (gfd)
Operating Time (Days)
39
35
30
25
20
15
10
5
10
15
20
25
REVERSE OSMOSIS TEST AT 750 PSIG WITH
FILTERED WASTE WATER FOLLOWING 10 DAYS CONDITIONING
3241-65-401

Figure 27

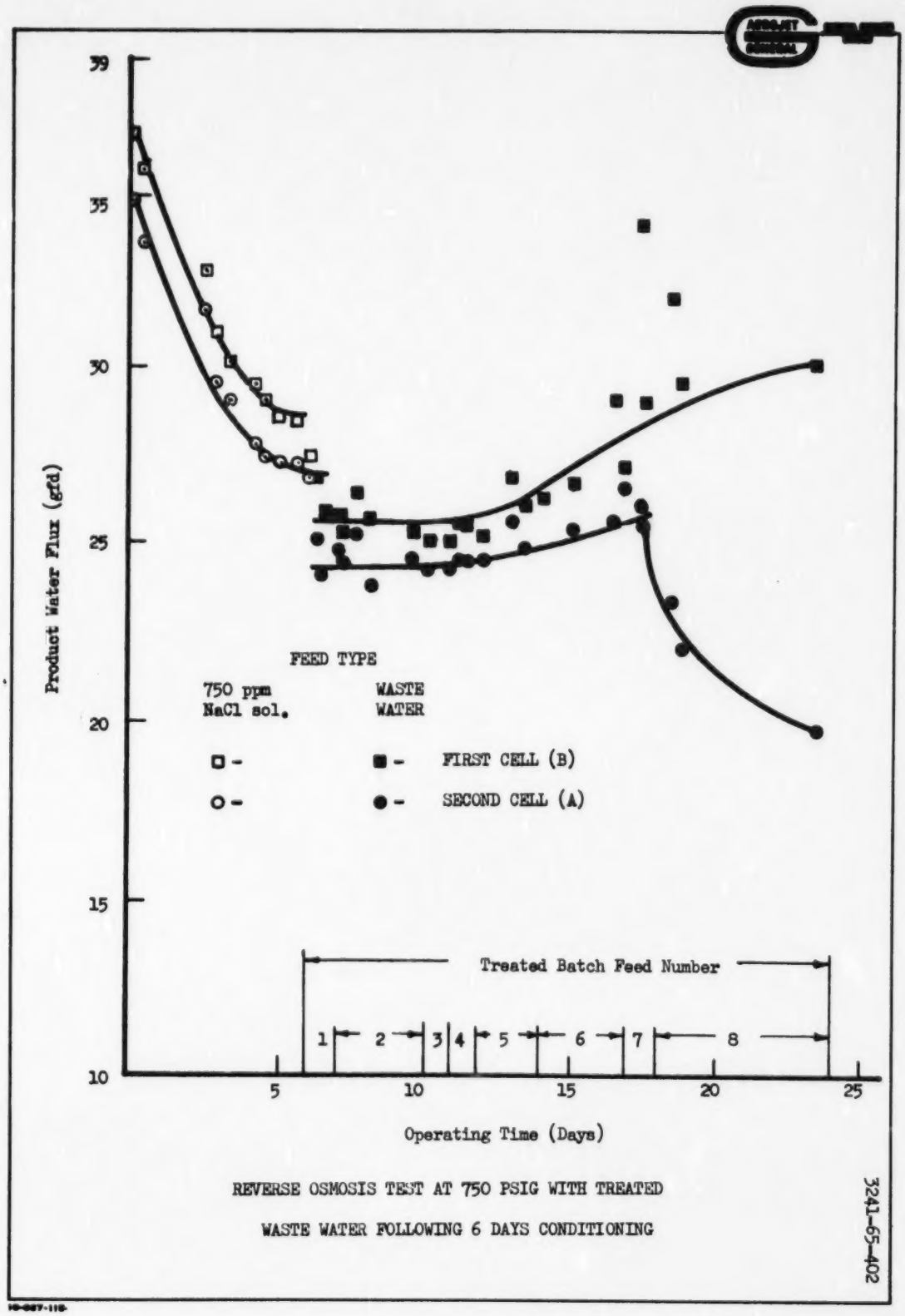

Product Water Flux (gfd)
39
35
30
25
20
15
10
FEED TYPE
750 ppm NaCl sol.
WASTE WATER
□ -
■ - FIRST CELL (B)
○ -
● - SECOND CELL (A)
Treated Batch Feed Number
1
2
3
4
5
6
7
8
5
10
15
20
25
Operating Time (Days)
REVERSE OSMOSIS TEST AT 750 PSIG WITH TREATED
WASTE WATER FOLLOWING 6 DAYS CONDITIONING
3241-65-402

Figure 28

CHEMICAL PRODUCTS DIVISION

REVERSE OSMOSIS AS A TREATMENT FOR WASTE WATER

A FINAL REPORT TO

U.S. PUBLIC HEALTH SERVICE

CONTRACT NO. 86-63-227

REPORT NO. 2962 / JANUARY 1965 / COPY NO.

APPENDIX A

ANALYTICAL PROCEDURES

The analytical procedures outlined in "Standard Methods for the Examination of Water and Waste Water", 11th Edition, have been followed without deviation in most cases. However, the previous experience of this laboratory had shown that some changes could be made, either to improve or simplify the procedures. These changes or alternate methods are herewith discussed. All analytical procedures were carried out in duplicate, except for TDS and ABS analyses.

1. Sodium and Potassium

The suggested method did not provide specific directions for removing interferring ions. In waste waters, interference could be expected from $PO_4^{\equiv}$, $SO_4^{=}$ Ca^{++}, and Mg^{++} ions. The Mg^{++} and Ca^{++} ions would interfere only if they were in concentrations of over 100 ppm, whereupon reference curves were prepared for use with recycle feed.

The major anion interference could be expected from $PO_4^{\equiv}$ and $SO_4^{=}$; these ions were removed from the water in the following manner. A 0.2% solution of $Pb(NO_3)_2$ was added to the water. This precipitated the $PO_4^{\equiv}$ and $SO_4^{=}$ as well as $CO_3^{=}$. The excess lead was removed by adding a 0.3% solution of $BaCO_3$. The precipitate was allowed to settle overnight and Na^+ and K^+ ions were determined on the supernatant liquid.

To verify this procedure, treated standards were compared with untreated standards. Using a 50 ppm standard of Na^+ for 100% transmittance point, a 30 ppm standard gave 79.6% transmittance and 79.5% transmittance for treated and untreated standards, respectively; therefore, sample treatment with $Pb(NO_3)_4$ does not interfere with transmittance.

Values obtained from actual samples before and after being treated by this procedure are shown below; a suppressing effect by the removed ions was observed.

	Treated	Untreated
Na	82.5 ppm	70 ppm
K	20.0 ppm	16 ppm

2. Calcium and Magnesium

A minor deviation in the method, described in "The Analytical Uses of Ethylenediaminetetracetic Acid", was employed, which involves determining both metals in one sample. Calcium was determined first using Murexide indicator at pH 12. The Murexide was destroyed with HCl, the pH adjusted to 10, and magnesium determined with Eriochrome Black T indicator.

3. Chloride

Chloride was determined potentiometrically employing a silver and glass electrode system with a Beckman Automatic Titrator.

4. Sulfate

An attempt was made to determine sulfate colorimetrically using barium chloranilate.[1] The method indicated interference from Al^{+++}, Ca^{++}, Fe^{+++}, and Pb^{++} ions which completely precipitated the acid-chloranilate ion. This was confirmed by adding standard sulfate to waste water samples. The resulting solutions were practically colorless indicating the presence of one or more of the interfering ions. It is possible to remove these ions with an ion exchange column; however, since the $BaSO_4$ gravimetric method was preferred, it was decided that development work on the chloranilate method was not justified. The gravimetric method was employed on all test samples.

5. Phosphate

The phosphovanadomolybdate[2] method was substituted for the standard method only because this laboratory has had considerable experience with this procedure, and the materials needed for analysis were immediately available. With this method, orthophosphate and total phosphate may be determined separately. The orthophosphate was determined by reacting the reagents cold with no preliminary treatment; the total phosphate was obtained after oxidation of the sample with perchloric acid.

6. Silicate

A silicomolybdate method, similar to Method C, "Standard Methods", was employed rather than Method B because this laboratory has had more experience with the former.

As a test for possible interference with Method C, standard silicate was added to waste water samples as received. Values obtained showed complete recovery of the standard, indicating no interference.

7. Chemical Oxygen Demand

The Chemical Oxygen Demand (COD) was determined by the procedure in "Standard Methods" as modified by the Public Health Service for use by Advanced Waste Water Treatment research contractors (dated 14 March 1963). This procedure utilizes mercuric sulphate to eliminate chloride interference during dichromate oxidation.[3] Duplicate analyses were run.

8. Alkyl Benzene Sulfonates (ABS)

The surfactants (ABS) were determined by the Methylene Blue Method (page 245) using a Bausch and Lomb Spectronic 20 Colorimeter previously calibrated at 652 mμ .

9. Total Dissolved Solids

Total Dissolved Solids (TDS) was determined by Method A, page 326, Residue on Evaporation.

APPENDIX B

COST ESTIMATE FOR REVERSE OSMOSIS WATER RENOVATION PLANT

Basis:	Plant Size	-10,000,000 gal/day product
	Feed	-Waste water - effluent from secondary treatment plant - 600-800 ppm TDS, 50-90 ppm COD, 2-8 ppm ABS, 270 ppm alkalinity as $CaCO_3$
	Product Specifications	-80 ppm TDS, 10 ppm COD, 0.3 ppm ABS, pH - 6.0
	Product Recovery	-90% of feed
	Pressure	-750 psig
	Membrane Flux	-24 gal/sq ft-day

COST SUMMARY

I.	CAPITAL COSTS		
A.	Essential Plant Costs		
1.	Special Equipment, installed	$1,013,000	
2.	Standard Equipment, installed	514,000	
	Total Cost, Principal Items of Equipment		$1,527,000
3.	Erection and Assembly	458,000	
4.	Instruments	61,000	
	Total Cost, Essential Plant		$2,046,000
B.	Other Plant Costs		
5.	Raw Water Supply	56,000	
6.	Product Storage	100,000	
7.	Service Facilities	153,000	
8.	Contingencies	236,000	
9.	Engineering	259,000	
10.	Interest during Construction	114,000	
11.	Site	30,000	
12.	Working Capital	149,000	
	TOTAL COST, CAPITAL		$3,143,000
	Cost per Daily Product	31.4 cents/gal.	

II. OPERATING COSTS

A. Essential Operating Costs

1.	Fuel	0.0 cents/K gal
2.	Electric Power	6.03
3.	Steam	0.00
4.	Raw Materials	4.94
5.	Supplies	0.45
6.	Operating Labor	2.50
7.	Maintenance Labor	0.45
8.	Payroll Extras	0.45
	Total Costs, Essential Operating	-14.82 cents/K gal
9.	General and Administrative	1.02
10.	Amortization	7.04
11.	Taxes and Insurance	1.80
12.	Interest on Working Capital	0.18
	Total Costs, Operating	-24.86 cents/K gal

CALCULATIONS

I. CAPITAL COSTS

A. Essential Plant Costs

1. Special Equipment (Installed) (Renovation Cells)

a. Membrane Area Required

$$1 \times 10^7 \frac{\text{gal}}{\text{day}} \cdot \frac{1}{24} \frac{\text{sq ft-day}}{\text{gal}} = 416{,}000 \text{ sq ft}$$

b. Number of Modules Required

$$416{,}000 \text{ sq ft} \cdot \frac{1}{30000} \frac{\text{Module}}{\text{sq ft}} = 13.9 \text{ modules;}$$

assume down-time of one month per year for each module required

$$13.9 \cdot \frac{12}{11} = 15.2 = 15 \text{ modules}$$

c. Module Cost

Assume $C_x = C_a \left(\frac{S_x}{S_a}\right)^{0.6}$

Where

C_x = cost of 30,000 sq ft module

C_a = cost of actual 100 sq ft unit installed, factored for anticipated fabrication improvements

S_x = capacity of scaled-up unit (30,000 gal/day)

S_a = capacity of actual unit (100 gal/day)

$C_x = 2200 \left(\frac{30,000}{100}\right)^{0.6}$ = $67,500 per module

d. Total Cost of Renovation Cells

$67,500 · 15 = $1,013,000

(thus, cost of cells reduces to $2.25 per square foot of membrane surface)

Total Cost - Special Equipment, Installed - $1,013,000

2. Standard Equipment

a. Filtration Equipment, Feed Water

Assume that pressure filtration through sand is necessary for processing the feed water. Installed cost is estimated to be $30 per gal/min. (Zimmerman and Lavine, Chemical Engineering Costs, 1950, p. 286)

$$\text{Rate} = 10,000,000 \frac{\text{gal. product}}{\text{day}} \cdot \frac{10}{9} \frac{\text{gal feed}}{\text{gal product}} \cdot \frac{1}{1440} \frac{\text{day}}{\text{min}}$$

Rate = 7,720 gal/min

$$\text{Cost} = 7,720 \frac{\text{gal}}{\text{min}} \cdot \$30 \frac{\text{min}}{\text{gal}} = \$231,600 = \$232,000$$

b. Pumps

Assume pumps rated at 1225 gpm at 750 psig, number required is:

$$\frac{1 \times 10^7 \frac{\text{gal product}}{\text{day}} \cdot \frac{10 \text{ gal feed}}{9 \text{ gal product}}}{1225 \frac{\text{gal feed}}{\text{min}} \cdot 1440 \frac{\text{min}}{\text{day}}} = 6.3 \text{ pumps}$$

Assume that seven on-stream pumps and two spares are required:

Cost = 9 x $28,000 = $252,000

c. Acid - Handling Equipment

Equipment for unloading storing and utilizing acid to neutralize feed water estimated at $30,000, installed

Total Cost - Standard Equipment, Installed	$ 514,000
Total Cost - Principal Items of Equipment (PIE), Installed	$1,527,000

3. Erection and Assembly (30% of PIE)

0.30 . $1,527,000 $ 458,000

4. Instruments (4% of PIE)

0.04 . $1,527,000 $ 61,000

Total Cost - Essential Plant $ 2,046,000

B. Other Plant Costs

5. Raw Water Supply ($5/K gal per stream day)

$$10{,}000 \frac{\text{K gal}}{\text{day}} \cdot \frac{10}{9} \frac{\text{gal feed}}{\text{gal product}} \cdot \frac{\$5 \text{ day}}{\text{K gal}}$$ $ 56,000

6. Product Storage ($10/k gal per stream day)

$$10{,}000 \frac{\text{K gal}}{\text{day}} \cdot \frac{\$10 \text{ day}}{\text{K gal}}$$ $ 100,000

7. Service Facilities (10% of PIE)

0.10 x $1,527,000 $ 153,000

8. Contingencies (10% of 1-7 incl.)

0.10 x $2,355,000 $ 236,000

9. Engineering (10% of 1-8 incl.)

0.10 x $2,591,000 $ 259,000

10. Interest during Construction (4% of 1-9 incl.)

0.04 x $2,850,000 $ 114,000

11. Site ($3/K gal per stream day)

$10{,}000 \frac{\text{K gal}}{\text{day}} \cdot \frac{\$3 \text{ day}}{\text{K gal}} =$ $ 30,000

Total Cost-Plant Investment $2,994,000

12. Working Capital (60 days at Total Operating Cost)

$60 \times \frac{\$0.249}{\text{K gal}} \cdot 10{,}000$ K gals $ 149,000

Total Cost - Capital $3,143,000

Cost per daily production 31.4 cents/daily gal.

II. OPERATING COSTS

A. Essential Operating Costs

1. Fuel - none used in process

2. Electric Power

Assume 70% pump efficiency and 90% recovery of product from the feed

$$\text{Work} = (PV) = \frac{144\ P\ G_a\ P}{E \cdot 7.48 \cdot 33000} = \frac{P\ G_a}{1715\ E} \text{ hp}$$

Where

P = pressure, psia
W = work, horsepower
G_a = water pumped, gal/min
p = density, lb/cu ft
E = pump efficiency

$$W = \frac{750 \text{ psia} \cdot 7700 \frac{\text{gal}}{\text{min}}}{0.7 \cdot 1715} = 4800 \text{ hp}$$

Electrical equivalent of this pump work, per product unit is given by

$$4800 \text{ hp} \cdot \frac{1 \text{ kw}}{1.341 \text{ hp}} \cdot \frac{1 \text{ min}}{6950 \text{ gal}} \cdot \frac{1 \text{ hr}}{60 \text{ min}} \cdot \frac{1000 \text{ gal}}{\text{K gal}} =$$

8.62 kwh/K gal product

$$\frac{8.62 \text{ kwh}}{\text{K gal}} \cdot \frac{1 \times 10^7 \text{ gal}}{24 \text{ hr}} = 3590 \text{ kw}$$

therefore, charge rate is 7 mills/kwh and cost of electrical power is

$$\frac{8.62 \text{ kwh}}{\text{K gal}} \cdot \frac{\$0.007}{\text{kwh}} = 6.03 \text{ cents/K gal}$$

3. Steam - none required by process

4. Raw Materials

a. Water acidification

Assume adjustment of feed water pH to 5.5. Assume feed alkalinity at western average of 270 ppm as $CaCO_3$.

$$\text{Acid Required} = \frac{270 \text{ mg } CaCO_3}{\text{liter feed}} \cdot \frac{1}{50 \times 10^{-3}} \frac{\text{eq. } CaCO_3}{\text{mg } CaCO_3}$$

$$= 5.4 \times 10^{-3} \text{ eq } H^+/\text{liter feed}$$

For sulphuric acid

$$5.4 \times 10^{-3} \frac{\text{eq. H+}}{\text{liter feed}} \cdot \frac{3785 \text{ liter}}{\text{K gal}} \cdot \frac{1 \text{ lb.}}{454 \text{ g.}} \cdot \frac{49 \text{ lbs } H_2SO_4}{\text{lb. eq.}} \cdot \frac{10 \text{ gal feed}}{9 \text{ gal prod.}} = 2.45 \text{ lb } H_2SO_4 \text{ /K gal prod.}$$

Cost of sulphuric acid required at $15.60/ton of 60° Baume
(C & E News Q'ly Price Index, October, 1963)

$$\text{Acid Cost} = 2.56 \text{ lb } H_2SO_4 \cdot \frac{1 \text{ lb. solu.}}{0.777 \text{ lb. } H_2SO_4} \cdot \frac{\$15.60}{2000 \text{ lbs solu.}}$$

$$\text{K gal prod.}$$

= 2.42 cents/K gal product

b. Membranes

Cost estimated at 10 cents/sq ft and assumed useable for 5-1/2 months

$$\text{Membrane Cost} = 416{,}000 \text{ sq ft} \cdot \frac{\$0.10}{\text{sq ft}} \cdot \frac{1}{165 \text{ days}} \cdot \frac{1 \text{ day}}{10{,}000 \text{ K gal}}$$

= 2.52 cents/K gals

Total Cost - Raw Materials 4.94 cents/K gals

5. Supplies (0.0015% of Total Plant Investment)

$$\text{Cost} = \frac{1.5 \times 10^{-5} \cdot \$2{,}994{,}000}{10{,}000 \text{ K gal}} = 0.45 \text{ cents/K gals}$$

6. Operating Labor

Continuous operation: requires 4.2 man-weeks $\left(\frac{168 \text{ hr}}{\text{week}}\right) \cdot \frac{1}{40} \left(\frac{\text{week}}{\text{hr}}\right)$ for each man required to operate the plant. Assume fraction is provided by overtime, raising requirement to 4.3 man-weeks/operator. Assume that 3 men are required to operate the plant on each shift, this labor to include membrane mounting.

$$\text{Operating Labor Cost} = \frac{\frac{4.3 \text{ man weeks}}{\text{man}} \cdot \frac{3 \text{ men}}{\text{shift}} \cdot \frac{\$3.00}{\text{hour}} \cdot \frac{40 \text{ hr}}{\text{week}}}{7 \frac{\text{days}}{\text{week}} \cdot 1000 \frac{\text{K gal}}{\text{day}}} =$$

2.21 cents/K gal

$$\text{Supervision Cost} = \frac{\$200/\text{week}}{7 \frac{\text{day}}{\text{week}} \cdot \frac{1000 \text{ K gals}}{\text{day}}} = 0.29 \text{ cents/K gals}$$

Total Cost - Operating Labor —— 2.50 cents/K gal

7. Maintenance Labor (0.0015% of Total Plant Investment)

$$\text{Cost} = \frac{1.5 \times 10^{-5} \cdot \$2{,}994{,}000}{10{,}000 \text{ K gals}} = 0.45 \text{ cents/K gals}$$

8. Payroll Extras (15% of items 6,7)

$$\text{Cost} = 0.15 \cdot 2.95 \frac{\text{cents}}{\text{K gals}} = 0.45 \text{ cents/K gals}$$

Total Costs- Essential Operating——14.82 cents/k gal

B. Other Operating Costs

9. General and Administrative Overhead (30% of items 6, 7, 8)

$$\text{Cost} = 0.30 \cdot \frac{3.40 \text{ cents}}{\text{K gals}} = 1.02 \text{ cents/K gals}$$

10. Amortization (0.0224% of Total Plant Investment)

$$\frac{2.24 \times 10^{-4} \cdot \$3,143,000}{10,000 \text{ K gals}} = 7.04 \text{ cents/K gal}$$

11. Taxes and Insurance (0.006% of Total Plant Investment)

$$\frac{6 \times 10^{-5} \cdot \$3,143,000}{10,000 \text{ K gals}} = 1.80 \text{ cents/K gals}$$

12. Interest on Working Capital (0.012% of Working Capital)
(calculated as 0.00725 . items 1-11, incl.)
0.00725 . 24.68 cents/K gal = 0.18 cents/K gals

Total Costs, Operating ——————24.86 cents/K gal

REFERENCES

1. Bertolacini, R. J., and Barney, J. C., Anal. Chem., 29, 281-83 (1957)
2. Snell and Snall, Colorimetric Methods of Analysis, 3rd Ed., Vol. II, (1949) pp 672-74
3. Dobbs, R. A. and William, R. T., Anal. Chem., 35, 1064 (1963)